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REPORT ON RESEARCH AT AFCRL

Air Force Cambridge Research Laboratories
L.G. Hanscom Field, Massachusetts

November 1967

REPORT

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Air Force Cambridge Research Laboratories

REPORT ON RESEARCH

For the Period July 1965 — June 1967

AFCRL-68-0039

Report on Research at AFCRL

JULY 1965—JUNE 1967

SURVEY OF PROGRAMS AND PROGRESS

THE AIR FORCE CAMBRIDGE RESEARCH LABORATORIES

OFFICE OF AEROSPACE RESEARCH

BEDFORD MASSACHUSETTS

NOVEMBER 1967

Foreword

This is the fourth in a series of reports issued every two years covering the research programs of the Air Force Cambridge Research Laboratories. The report was written for the Air Force and DoD managers of research and development. We have made certain suppositions with respect to this audience and one of these is that it is technically informed to a marked degree. Through formal scientific and technical training, and through long association with military R&D programs, the military R&D manager brings considerable sophistication to his evaluation of the merit of certain programs. In addressing this audience, there is no need to dwell unduly on the connection between investigation and its relevance to enhanced Air Force capability. Although we often state these connections explicitly, just as often we assume the connections to be implicit. Another supposition is that the reader has a general awareness of the state of the art in a particular field. We therefore undertook to discuss the various programs at AFCRL in sufficient technical depth to permit the reader to make fine distinctions between these programs and related programs conducted elsewhere. Curiously, one discovers that after establishing the various assumptions, guides, and criteria for a report meaningful to the military R&D manager, the criteria have equal validity to a much broader class of reader. This report may be of interest and value to all those who may wish to obtain a reasonably complete account of research programs of the Air Force Cambridge Research Laboratories and of the progress made under these programs during the period July 1965 through June 1967.

ROBERT F. LONG
Colonel, USAF
Commander

Contents

I Air Force Cambridge Research Laboratories

The Air Force Cambridge Research Laboratories are an element of the United States Air Force. These Laboratories are the center for Air Force research in the environmental sciences—research that includes geology, geodesy, meteorology, upper atmosphere chemistry and dynamics, solar phenomena and properties of near space. AFCRL is also a center for electronics research with its programs concentrated in solid state sciences, data processing and information sciences, and microwave physics.

The total AFCRL program extends from fundamental studies at one end of the R&D spectrum to equipment development at the other, but the center of gravity of the total program is toward the basic research area. In terms of people, almost one-half of AFCRL's complement of 1100 is identified with basic research as defined under the DoD designation, Defense Research Sciences (614). In terms of budget, about a quarter of the FY-1967 contract budget was expended under this DoD category.

The period of this report, July 1965 through June 1967, saw AFCRL give increasing attention to well-specified problems associated with military operations in Vietnam—this a reflection of the nation's Southeast Asia commitments. At the conclusion of the period, AFCRL was conducting some 24 separate studies relating to these operations.

The main laboratory buildings of AFCRL are located at L. G. Hanscom Field which is operated by the Air Force Systems Command. AFCRL, with a

separate chain of command, is a tenant on the Field. Hanscom Field stretches across parts of four Massachusetts communities at a point about 20 miles west of Boston. These communities are Bedford, Concord, Lexington and Lincoln. AFCRL is one of three major research and development organizations located on Hanscom Field. The other two are MIT's Lincoln Laboratory, less than a quarter mile distant from AFCRL, and the Electronic Systems Division (ESD) of the Air Force Systems Command, which is the largest of the three organizations.

Immediately outside the limits of Hanscom Field is the Mitre Corporation, a not-for-profit R&D organization set up to assist ESD in its various system development programs. Hanscom Field itself is located just off Route 128 along which a substantial part of the nation's total electronics and industrial research capability is located.

ROLE AND MISSION: The mission of AFCRL is to conduct research in the environmental sciences and in certain areas of the physical sciences that bear —immediately or potentially—on Air Force operations. The AFCRL program is largely formulated around defined or anticipated Air Force needs and requirements. But "requirements" imply a known state of the art. As such, program formulation purely on the basis of formally stated requirement documents inhibits distant vision. Part of the AFCRL mission, therefore, is to conduct research that may lead to the establishment of new requirements. In the broadest possible context, most Air Force

AFCRL is located at L. G. Hanscom Field, about 20 miles west of Boston. The AFCRL complex is in the foreground. Beyond is the Lincoln Laboratory, marked by white radome.

requirements fall under such headings as reconnaissance, surveillance, detection, communications, information processing and use, and aircraft and missile operations. All AFCRL programs can be assigned to one or more of these requirements.

AFCRL is an in-house laboratory. This might be taken to mean that all of its programs are wholly carried out by AFCRL personnel. This is not the case at AFCRL—or at any large research laboratory. A design concept, for example, may originate in-house, but a practical working instrument or device based on this concept may be completed by others under contract. In-house research, as viewed by AFCRL, is research that it conceived by, formulated by, directed by, and conducted at least in part by an AFCRL scientist. This scientist is ordinarily responsible for final data analysis and interpretation—but even in this respect he may be helped by others under contract.

AFCRL scientists often serve as Air Force and DoD advisors in many areas of science and technology. AFCRL scientists serve on more than 45 Air Force, DoD, other Governmental and international committees, boards, study groups and panels. These groups have a number of functions: to evaluate systems concepts, to shape military programs, to coordinate activities and programs, or simply to provide a forum for the exchange of information and views.

AFCRL is to the Air Force and its operational elements as a corporate research laboratory is to the company's manufacturing elements. Much management philosophy has been set forth on these relationships. No elaboration on the main themes of this philosophy will be attempted here. But certain questions, perhaps unanswerable, may serve to illuminate AFCRL's role. A basic question in research management is how

From left: AFCRL Commander Colonel Robert F. Long, OAR Commander Major General Ernest A. Pinson and Brigadier General Leo A. Kiley, former AFCRL Commander, who succeeded General Pinson as Commander of OAR.

a research laboratory maintains a sensitive response to the needs and goals of the organization that supports it without compromising the scientific environment essential to viable, productive research. A related question involves the coupling of the product of research to the needs of development and operational agencies. Is the obligatory burden of coupling discharged with the dissemination of research results in the literature. Few would argue that it is.

Several active programs—as against the passive dissemination of research results—have been undertaken to bring the AFCRL product to the attention of the user. Two of these are managed by AFCRL's headquarters agency, the Office of Aerospace Research. One program consists of a series of coupling conferences in which AFCRL scientists visit Air Force development and operational units to get a better picture of user needs and to present research results. The second activity is the annual

OAR Research Applications Conference held in Washington, D. C., to which representatives from defense industries, government and military agencies, and Air Force units are invited to hear presentations on recent research results promising expanded capabilities.

A more direct research-user cooperative program inaugurated during the period was the establishment within AFCRL of an Environmental Consultation Service. Part of this service is information—supplying data to military users on the terrestrial, atmospheric and space sciences, and advising on electromagnetic propagation and plasma problems. But the more meaningful aspect is that of assisting development and user agencies in the planning, design and development of operational and test procedures in areas where environmental influences come into play.

The AFCRL program is monitored by OAR's Scientific Advisory Group, a panel of which is pictured here during a meeting at AFCRL.

To give greater substance to the Environmental Consultation Service, an agreement was reached with the 6th Weather Wing of the Air Weather Service under which staff meteorologists at 14 Air Force Systems Command organizations were also named AFCRL staff meteorologists, and thus were formally attached to AFCRL. This agreement establishes a direct tie between AFCRL and Air Force users of environmental data.

OFFICE OF AEROSPACE RESEARCH: The Air Force Cambridge Research Laboratories report to the Office of Aerospace Research (OAR). OAR has its headquarters in Arlington, Virginia, and in turn reports directly to the Chief of Staff. OAR is responsible for the Air Force research mission, and is organizationally separated from the Air Force development activity which is the responsibility of the Air Force Systems Command.

AFCRL is the largest of the several research laboratories and offices administered by the Office of Aerospace Research. In terms of people, OAR headquarters, together with all the laboratories under its command, numbers about 2000 persons. Of this number, about 1100 (as of June 30, 1967) are at AFCRL.

Other units comprising OAR are the Air Force Office of Scientific Research, in Arlington, Virginia, which relies primarily on grants in carrying out external research across many disciplines; the Aerospace Research Laboratories, at Wright-Patterson AFB, Ohio, an in-house research laboratory working in the fields of physics, chemistry, metallurgy, thermo-mechanics, hypersonics and fluid dynamics; the Frank J. Seiler Research Laboratory, located at the USAF Academy, Colorado, engaged in chemistry and mechanics, and the Office of Research Analyses, located at Holloman AFB, New Mexico, concerned with research and systems analysis. In addition, OAR maintains small liaison offices at Patrick AFB, Florida, and Vandenberg AFB, California, and at the Space and Missile Systems Organization

(SAMSO) in Los Angeles. Foreign operations are conducted through offices in Brussels and Rio de Janeiro.

The Office of Aerospace Research, during most of the period of this report, was under the command of Major General Ernest A. Pinson, who succeeded Major General Don R. Ostrander on October 15, 1965.

Subsequent to the time period of this report, on November 1, 1967, General Pinson was named Commandant of the Air Force Institute of Technology. Former AFCRL Commander Brigadier General Leo A. Kiley was named new OAR Commander, effective on January 15, 1968.

ORGANIZATION AND PERSONNEL: On October 18, 1965, Colonel Robert F. Long was appointed Commander of the Air Force Cambridge Research Laboratories, succeeding Brigadier General Leo A. Kiley. During the period of this report, the AFCRL Vice Commander was Colonel James L. Dick. On July 1, 1967, he was appointed Commander of AFSC's Avionics Laboratory. Appointed new AFCRL Vice Commander at that time was Colonel Orville J. Kvamme.

AFCRL is made up of nine laboratories organized along disciplinary lines. But in the special sense that the research in each laboratory is related to present and anticipated Air Force needs, the Laboratories are mission-oriented. This duality is common to almost all research laboratories, even those associated with universities. Such laboratories tend to be organized along disciplinary lines, while functionally much work is mission-oriented.

The nine AFCRL laboratories are the Data Sciences, Microwave Physics, Aerospace Instrumentation, Space Physics, Meteorology, Terrestrial Sciences, Optical Physics, Upper Atmosphere Physics, and Solid State Sciences Laboratories.

During the reporting period, AFCRL established an office on the West Coast in El Segundo, California, to maintain closer liaison with the Air Force's Space Systems Division and Ballistic Systems Division (combined on July 1, 1967 and redesignated the Space and Missile Systems Organization). The AFCRL West Coast Office was set up to effect a closer coordination of SAMSO and AFCRL programs.

During the reporting period, AFCRL sponsored 18 scientific conferences and was host to several hundred visitors such as the group of South Vietnamese officers pictured below during a tour of AFCRL facilities.

As of June 30, 1967, the AFCRL personnel complement was 1102—195 military and 907 civilian. But this figure does not fully reflect AFCRL size. Much administrative support—procurement, personnel, maintenance, and so on—is furnished by the AFSC Electronic Systems Division at L. G. Hanscom Field. AFCRL receives, altogether, some 23 different services from ESD. In terms of people, this support constitutes about 345 man years. About one-third of this number goes into the procurement and supply functions. Furthermore, much of AFCRL's work could not be done without the help of personnel from other Air Force agencies—the Air Weather Service, and the personnel at the various Air Force rocket and missile ranges. The turnover rate of AFCRL scientific personnel is about 5 percent a year, a percentage somewhat lower than the national average for research laboratory personnel.

In FY-1968, an additional 140 manpower spaces will be allocated to AFCRL, bringing AFCRL's personnel complement to 1242. This new manpower allocation does not represent an expansion of the AFCRL program. The additional manpower spaces will be allocated in substitution for a substantial cutback of contractual personnel who during previous years worked within the AFCRL laboratories under the "Associated Research Contracts" program.

Almost 600 AFCRL employees have degrees—212 bachelors, 220 masters and 135 doctorates. The 135 doctorate figure represents a decrease of six from the figure of two years ago.

FY-1966 AND FY-1967 BUDGETS: Budgets are best understood in the context of historic trends. The largest budget in AFCRL's history was that of FY-1963 when the Laboratories received $74.5 million to conduct their program. The FY-1968 budget is not expected to exceed $50 million. For the intervening four years, beginning with FY-1964, the AFCRL budget was $66.7 million, $58.2 million, $62.2 million and $58.5 million, respectively. If the FY-1968 budget does in fact fall below $50 million as expected, it will be more than $8 million below the budget for the preceding year. The cut actually goes deeper because of rising overhead expenditures—salaries, supplies, equipments, and so on.

The decrease in the AFCRL budget is primarily a result of the nation's Southeast Asia and domestic commitments. Although no one willingly accepts a cut in funding, the impact of the cut is somewhat absorbed by the AFCRL contract program. The in-house research program will not be strongly affected, although AFCRL's rocket, satellite and balloon programs will be reduced. The effect of the budget decrease will be to increase the percentage of the total AFCRL program that is conducted in-house against that which is conducted under contract.

The AFCRL budget is derived from many agencies. Sources of FY-1966 and FY-1967 funds are shown in the accompanying tables. The budget figures given in these tables are not intended to represent a total cost accounting for operating AFCRL. Not reflected in these figures are salaries of military personnel, services provided by the Electronic Systems Division, and assistance in conducting field operations given by other Air Force and Government agencies. The figures include the money received by AFCRL for contract research, civilian salaries, equipment, travel and general operational costs. About $13 million of the FY-1967 budget was expended for civilian salaries.

The funds received from AFCRL's headquarters, OAR, and to a lesser extent those received from AFSC, are

TABLE 1
SOURCES OF FY-1966 FUNDS

OAR		$44,773,000
AFSC		10,320,000
R&T Div.	$4,450,000	
Avionics	2,563,000	
RADC	367,000	
ESD	2,363,000	
SSD	517,000	
AFWL	50,000	
ASD	10,000	
ARPA		3,418,000
DASA		1,847,000
NASA		1,532,000
NSA		161,000
ARMY		54,000
NAVY		50,000
USCG		46,000
NSF		25,000
Dept. of Commerce		10,000
TOTAL		$62,236,000

TABLE 2
SOURCES OF FY-1967 FUNDS

OAR		$47,093,578
AFSC		4,661,487
Avionics	$1,674,734	
RADC	1,384,539	
ESD	1,130,158	
SSD	286,000	
ASD	104,606	
AFWL	27,500	
BSD	53,950	
ARPA		3,234,328
NASA		1,559,748
DASA		1,426,660
NSA		172,513
AFLC		129,000
ARMY		63,413
DCA		27,146
NAVY		13,655
USCG		11,000
AFFTC		5,000
Dept. of Commerce		4,000
TOTAL		$58,406,528

used to conduct programs of a continuing long range nature. More discretion is provided AFCRL administrators and scientists in the expenditure of funds from these two sources than is allowed in the expenditure of funds from other sources. Funds from other agencies are earmarked for specific research projects.

More than half of the AFCRL budget during the reporting period was spent for contract research. The total number of outstanding contracts changes from month to month, but the average is about 900, with the average value of each contract being small relative to the average value of the contracts of Air Force development agencies. As of June 30, 1967, AFCRL had 905 contracts outstanding. Of these, 389 were with industrial concerns, 290 were with U. S. universities, and 126 were with foreign universities and companies. The remaining 100 contract documents were with research foundations, other Government agencies and for special procurement actions.

The character of AFCRL's contract program differs substantially from the contract programs of most other Government R&D laboratories. AFCRL contracts almost always call for work that is in direct support of research carried out within AFCRL. They are managed by scientists who are themselves active, participating researchers, and who plan the research, initiate a line of inquiry, organize the program, interpret the results and share the workload of the actual research.

FACILITIES AND FIELD SITES: AFCRL permanent installations are located in 17 different places. In terms of acreage owned, leased or occupied by use agreement, AFCRL occupies 944 acres of land. Most of the AFCRL permanent sites are located within a radius of 60 miles from Hanscom Field. The most

recent of these installations, one placed in operation during the reporting period, is a new lunar observatory in Concord, Mass. The observatory houses a 24-inch telescope. The largest local site is the Sagamore Hill Radio Observatory in Hamilton, Mass., where AFCRL operates two large radio telescopes, one with an 84-foot dish, the other with a 150-foot dish. Another large off-base site is AFCRL's weather radar research facility in Sudbury, Mass. Other sites in the Massachusetts area are a large antenna range and a satellite telemetry receiving facility (using a 60-foot antenna) both in or near Ipswich, Mass.

Outside the Massachusetts area, AFCRL operates permanent sites in New Mexico and California. One of AFCRL's two balloon launch facilities is located in New Mexico, at Holloman AFB. Nearby, at Sunspot, New Mexico, is AFCRL's Sacramento Peak Observatory, one of the largest and most completely instrumented solar observatories in the world. Construction of a new vacuum telescope at Sacramento Peak was begun during the period (see Chapter III) and is scheduled for completion in 1968. At Chico, California, is located AFCRL's second balloon launch facility.

In addition to these permanent AFCRL sites, two other sites where AFCRL scientists conduct important experiments warrant attention. AFCRL is the major user of three high resolution radars at Wallops Island, Virginia, where observations are made of clear air convective currents and of atmospheric conditions associated with clear air turbulence. The second site is located at Thule, Greenland, a site which AFCRL has maintained with contractor personnel for more than a decade to assemble a continuous record of Arctic geomagnetic data.

Several temporary field sites were set up for special observations during the July 1965–June 1967 period. Two temporary sites, at Liberal and Manhattan, Kansas, date back to the preceding period. These sites were used to study microscale meteorological phenomena. Some of these temporary sites were used for a period of a month or so, others may continue in operation for several years. Sites for wave propagation studies were established in American Samoa and Panama; sites were established at Vega Baja, Puerto Rico, for a series of rocket launches to investigate ionospheric winds; a site was established in Greece for the annular solar eclipse of May 20, 1966. For the eclipse of November 12, 1966, which traced a path across South America, AFCRL established sites in Brazil, Bolivia and Peru. Instrumented trailers are usually the central facility of AFCRL's temporary field sites. Some 45 trailers are used by AFCRL. A particular trailer may be transported to three or four different locations all over the world during any two-year interval.

For foreign operations where diplomatic clearances are required, AFCRL must plan well in advance with the State Department and with foreign governments. Surveys must often be made of the test area prior to organizing an expedition. Where feasible, AFCRL attempts to plan the observations as a cooperative endeavor with scientists of the country in which a particular experiment is being conducted.

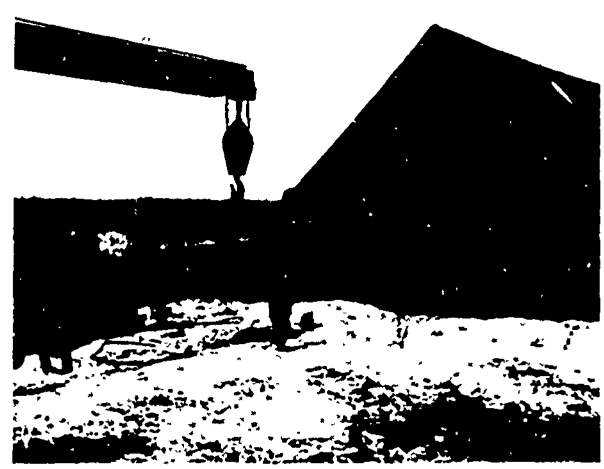
SATELLITES, ROCKETS, BALLOONS AND AIRCRAFT: AFCRL is the largest developer and user of research balloons in the country. From its balloon launch sites at Holloman AFB, New Mexico, and Chico, California, the Laboratories launch about 170 large balloons each year. More than 300 were launched during this reporting period.

AFCRL-designed experiments were carried aboard 25 different satellites during the two-year period. Four of these satellites were instrumented solely by AFCRL, with the remainder being packages carried aboard NASA and Air Force satellites. AFCRL flew experiments aboard Gemini 5, 7, 10 and 12, and NASA's OSO and OGO series of satellites.

Also during the period, AFCRL launched 104 rockets. Of these, 66 were launched by one AFCRL laboratory, the Upper Atmosphere Physics Laboratory. AFCRL also had packages aboard four missiles.

Most of the rockets were launched from three sites—45 from the Air Proving Ground Center at Eglin AFB, Florida, 17 from the White Sands Missile Range in New Mexico, and 16 from Ft. Churchill, Canada. Four of the rockets were launched from Rio Grande, Brazil, during the solar eclipse of November 12, 1966.

AFCRL experiments are conducted all over the world. Above a camera crew from a West German TV station visits a temporary AFCRL field site in Greece set up to observe the solar eclipse of May 20, 1966. Below, a temporary rocket launch site established in Alaska for auroral observations.



Rockets launched during this period were used to examine almost every aspect of the earth's upper atmosphere and near-space environment. The largest programs can be grouped under certain broad categories—atmospheric winds, temperatures and densities; the electrical structure of the ionosphere; solar ultraviolet radiation; atmospheric composition; the earth's radiation belts; cosmic ray activity; airglow and the aurora.

Since AFCRL launched its first rocket in August 1946—an early V-2—the Laboratories had launched a total of 641 rockets as of 30 June 1967. This figure, which does not include an even larger number of smaller meteorological rockets, is the largest number of sounding rockets launched by any group or laboratory in the country and, by safe inference, in the world. The AFCRL program has given the aerospace and scientific communities a detailed picture of the earth's dynamic environment.

AFCRL has a fleet of five instrumented aircraft—two KC-135s and three C-130 aircraft. A U-2 aircraft, used in past years for meteorological

During the two-year period of this report AFCRL instrumented and launched 104 rockets, and placed research payload packages aboard 25 different Air Force and NASA satellites.

observations, was withdrawn from AFCRL use during the period. One of the KC-135s and one of the C-130s are instrumented for measuring the transmission, scattering and reflectance of optical radiation in the atmosphere. The use of the KC-135 for these observations began in the spring of 1967 following a major reinstrumentation of this aircraft at the cost of a third of a million dollars. With a range of spectrometers, interferometers, cameras and on-board recording and processing equipments, it is one of the most completely equipped flying laboratories in the world. AFCRL's other KC-135 is instrumented for ionospheric observations. The second of the three C-130s is used for meteorological research, while the third is instrumented for two programs—airborne geological surveys and airborne gravity measurements.

SERVICES: The dimensions of a research laboratory can be defined indirectly by reviewing the quality of services available to the scientist. The researcher is interested foremost in computational, engineering and library services. He is also interested in the editing, publication and dissemination of his research results. Where extensive field operations are involved, as they are at AFCRL, he is interested in the logistic support needed to locate and prepare field sites and transport equipment.

The magnitude of the AFCRL logistic support function is strongly implicit in the foregoing discussion of AFCRL field sites and the instrumentation of satellites, rockets, balloons and aircraft. With respect to the publication and dissemination of research results, the reader is referred to the listing of papers and reports at the conclusion of each Laboratory chapter. During the report period, AFCRL scientists published 460 papers in scientific journals, presented 611 papers at scientific meetings all over the world, and prepared 459 reports for in-house publication. With respect to in-house reports, the average distribution of each is about 500 copies. Information dissemination is further accomplished through the sponsorship of national and international conferences. During the period, AFCRL sponsored or cosponsored 18 such conferences.

For general computation, AFCRL's basic equipment is a dual computer system consisting of two computers, an IBM 7094-II and an IBM 7044, coupled together with common input and output equipments. This 7094-II/7044 direct couple system was placed in operation in December 1966.

In addition to these general service computers, several smaller, special purpose data processors are located in the various AFCRL laboratories. Prelim-

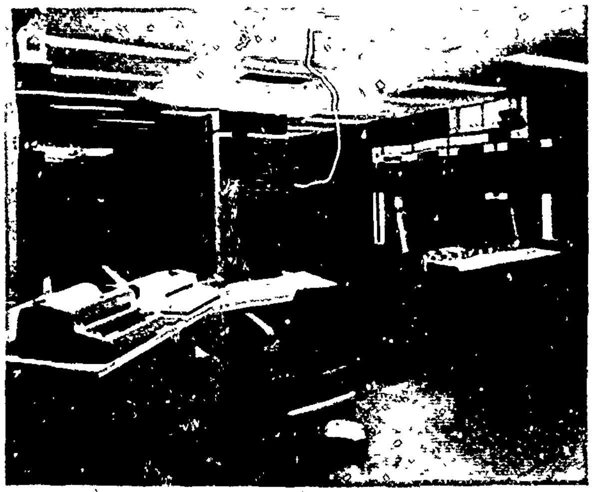
inary reduction of data from AFCRL's large rocket and satellite programs is often performed for AFCRL at the large computational facilities at Vandenberg AFB and at Cape Kennedy.

Throughout this report, one will find references to "special instrumentation" and to the design and fabrication of equipment for certain projects. Research engineering—the design, engineering and fabrication of "special" high precision or unique components—is a field to which neither scientists nor engineers, in general, give proper recognition. This is curious in view of the basic role these special components and instruments have in the success of any research endeavor. Scores of components—particularly those designed for rocket and satellite instrumentation—are fabricated by AFCRL engineers in-house each year.

The AFCRL library has grown into one of the finest research libraries in the world. Its geophysics collection is unexcelled. Each year the library acquires about 8000 new monographs and it regularly receives more than 4000 periodicals.

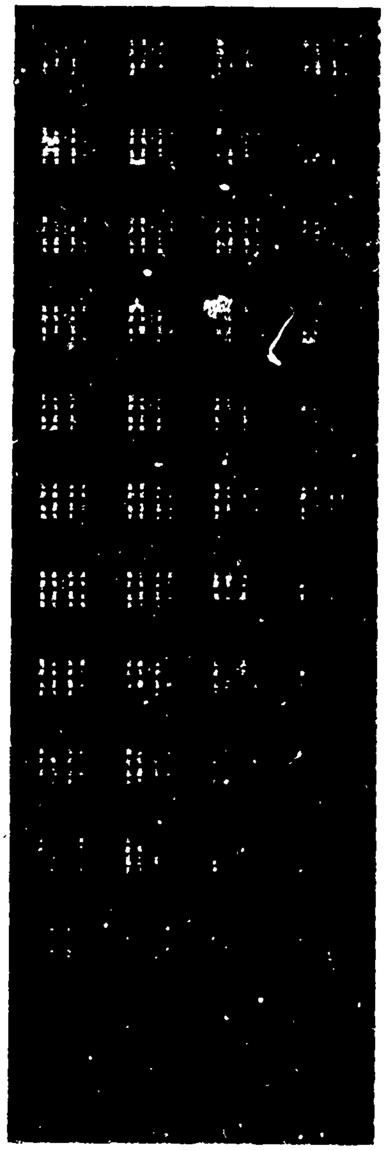
Visitors to the AFCRL library are most impressed by the library's historical collection. For example, the library has complete collections of the *Philosophical Transactions of the Royal Society of London* dating back to 1665, the *Histoire of the Paris Academy* dating back to 1699, and the *Commentarii of the Russian Academy of Science* dating back to 1726.

In addition, the library has acquired a large collection of original notebooks of the third and fourth Lords Rayleigh as well as nearly all of the manuscript material of both Lords Rayleigh. During the report period, the Rayleigh Collection was dedicated at a ceremony held at the AFCRL library and attended by the present Lord Rayleigh and several Nobel Laureates.



The basic equipment in AFCRL's computational center consists of IBM 7044 and 7049 computers linked together with common input and output terminals.

The dedication of the Rayleigh Archives at the AFCRL Research Library took place in the spring of 1966. From left are General Pinson, AFCRL Chief Scientist Dr. John N. Howard, Charles Strutt (son of the fourth Lord Rayleigh), Colonel Long, and Mrs. Strutt.



Since the late 1950's, AFCRL has been a major supporter of research that has led to the present state of the art in the design and fabrication of integrated circuits. Shown here is a segment of an array of individual eight-neighbor elements.

II Data Sciences Laboratory

The program of the Data Sciences Laboratory centers on the processing, transmission, display and use of information. Implicit in this program statement is an emphasis on computer technology. Network theory and circuit design, programming and languages, and information and communication theory all are parts of the total Laboratory program. The program also includes the application of computers to Air Force operations, with communications being the best example of such mission-oriented research.

Improved computer speed, versatility, logic density, and capacity are the general goals of all computer research. The pursuit of these goals takes the researcher in many diverse directions—into logic network analysis and circuit design, materials synthesis, new deposition techniques, device fabrication and so on.

In addition to these general goals, AFCRL gives special attention to methods for making more effective use of existing computers. Computers are capable of many more tasks than they are presently assigned, primarily because no one knows how to go about instructing the computer on how to do more difficult tasks. Realizing the full capability of computers requires a great deal of research on computer programming and languages. Much AFCRL emphasis is in this area. Through this emphasis, AFCRL hopes to provide a more natural interface between computer and operator, to improve man-machine communications, to sharpen the decision-making capabilities of the total man-machine system, and to uncover techniques that permit computers to assimilate directly

a variety of non-numerical data. The last of these includes pattern recognition and the direct processing of sensor data (radar, acoustic, infrared and so on).

A major program category is communications—in particular, the transmission and reception of speech signals. AFCRL's speech research program involves both the physiological mechanisms of human speech production, speech perception, and the machine processing of speech signals. The basic goal of the speech research program is that of transmitting speech over extremely narrow bandwidths. For a similar purpose—that of bandwidth reduction—the Laboratory is investigating television transmissions. Here the goal is to transmit pictures over narrow channels with a minimum of degradation in picture quality. Also in the area of communications, the Laboratory is seeking to transmit digital and analog data with maximum reliability (and minimum redundancy). This work falls into the research category of information theory.

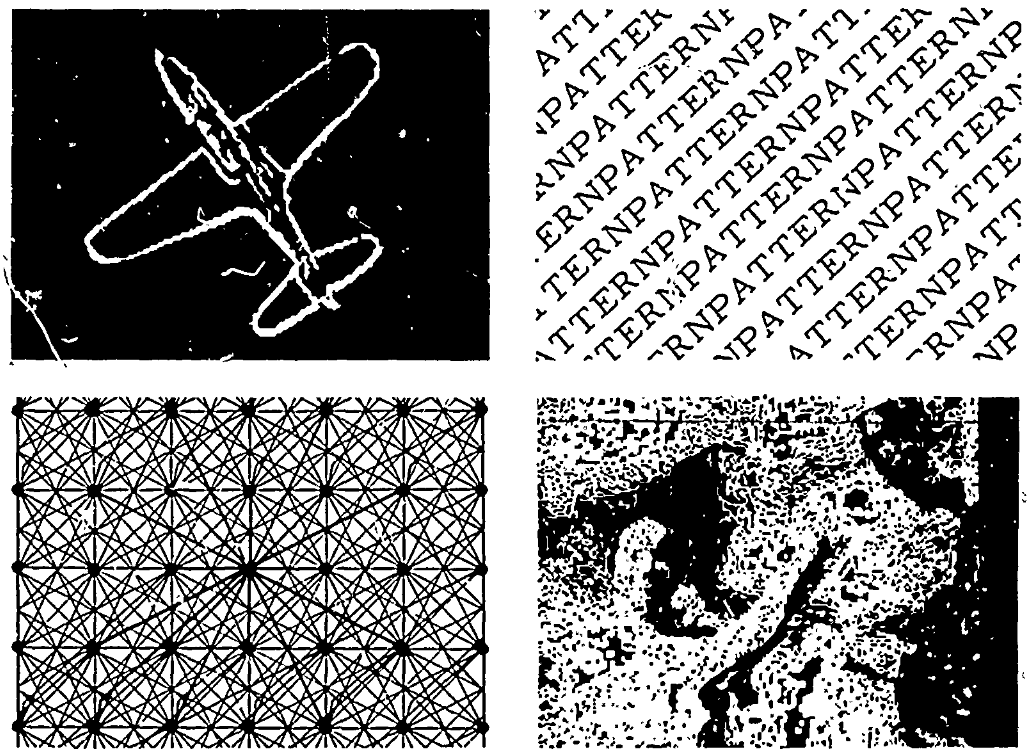
The biophysics program discussed in the previous *Report on Research* was largely discontinued during the present reporting period because of the loss of key personnel. The Laboratory nevertheless maintains a small residual effort concerned with the mathematical modeling of human biological rhythms.

In this experiment, AFCRL demonstrates that brain waves can be controlled voluntarily by eye position and fixation. Electrodes above and below the eye record eye movement. The wire across the shoulder leads to electrodes on the back of the head to record Alpha rhythm.

RECOGNITION PROCESSES

Recognition is a prerequisite for survival. It is the basic first step to categorization and generalization of the infinite phenomena that impinge upon man's senses. Recognition, classification, and situation analysis permit man to cope with his environment by integrating things into manageable groupings. The validity and effectiveness of his groupings determine how well he is able to function in his environment.

In observing the continuously varying, dynamic and diverse phenomena—the objects, situations, sound signals and so on, that make up the universe—he is at the same time taking measurements. He then—most often without conscious effort—determines whether his sets of measurements contain certain invariant characteristics, a "pattern" that allows him to classify this input as having a specified significance to him. Humans are proficient at this sort of thing; machines are not. The Data Sciences Laboratory and researchers at other places are heavily engaged



In observing the four photographs in this set (or in observing, hearing or sensing any object, source or situation) you are making measurements to determine whether the pictures contain invariant characteristics that permit classification. Humans are proficient at making such measurements; machines are not.

in research on various recognition processes.

Objects, situations and physical processes can be described in a multiplicity of ways. But in all cases, one seeks sets of invariant attributes which describe the pattern or process in the simplest and most effective way according to a set of specified criteria.

But this is not a simple task except, perhaps, when the data have definable statistical properties. Part of the problem is that the choice of the attributes most effective for classification depends not only on the nature of the input data but also on the subjective point of view of the classifier. This choice of proper attributes is not obvious, although in certain relatively simple cases an intuitive choice followed by tests to identify the most efficient attributes can be successful. In more complex situations, there are usually very few clues to attributes that describe best, from a classification point of view, the patterns in question. Often it proves necessary to apply transformations of the data that bring out previously hidden features, which is the process used in medial axis transformation and in statistical filtering, to be described later.

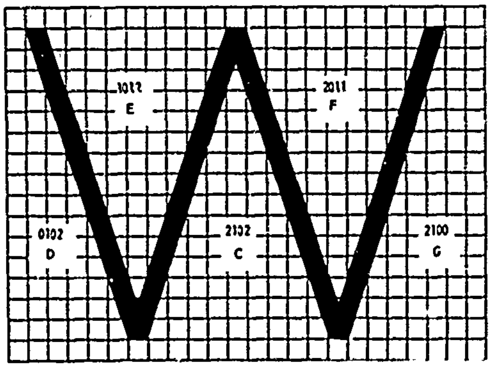
GENERAL DESCRIPTION OF COMPLEX PATTERNS: In dealing with complex patterns such as aerial photographs, conventional pattern classification schemes are often inadequate, either because the complexity of the pattern swamps the fixed-property-list approach usually employed in such classifications, or the desired processing may not be a simple classification of the pattern into one of a pre-selected set of categories, but a more complex manipulation, such as finding all instances of a specified subpattern.

A promising approach to such problems developed at AFCRL consists of constructing a "description" of the pattern in a form convenient for further computer manipulation. This description is the result of an analysis of the pattern in terms of a set of hierarchical definitions specifying subpatterns and how they are composed to form larger ones. These definitions are couched in terms of a set of primitives appropriate to the class of patterns to be analyzed. The process is in some respects analogous to the syntactic analysis of sentences, where the complex pattern responds to a sentence and the set of definitions to a grammar in terms of which the analysis is carried out.

A "language" for such definitions has been designed and a corresponding analysis program implemented (in LISP) and tested on several pattern classes. Present work (June 1967) is directed toward improving the pattern description formalism itself, constructing a more efficient analysis program, and applying the scheme to further classes of patterns.

CHARACTER RECOGNITION: Compared to the problem of automating a pattern recognition procedure for the complex patterns of the type described above, it would seem that the relatively uncomplicated task of automatically identifying printed letters and numbers on a page would be simple to implement. It has not proven so. Solutions have been elusive, although perhaps more research has been devoted to the problem of printed character identification than to any other aspect of pattern recognition. Objectives differ from place to place. AFCRL's objective is a system for identifying printed characters of a wide variety of sizes, orientations and fonts.

The AFCRL technique is based on a topological description by "characteristic loci." In the previous AFCRL *Report on Research* this scheme was described as containing a matrix of cells upon which the character in question is inscribed. Each cell looks left, up, and down and right and determines for each direction whether it "sees" the outline of the alphabetic character in that direction. A refinement has since been adopted by which each cell determines the number of intersections a ray drawn from the cell in each of these four directions makes with the line of the character. A code is assigned to each cell



A method of encoding a letter by the characteristic loci procedure is one involving the implantation of the letter on a matrix of cells. A code is assigned to each cell in the matrix depending on what it "sees."

depending on what it "sees." Thus, a cell located in the lower center cavity of a "W" (see Figure) has the code 2102 (two intersections to the left, one up, none down and two right). A pattern is said to be characterized when it is associated with others of the same class and distinguished from members of other classes by a vector whose components are the relative number of cells having each of the possible codes. For success, the pattern vectors of like characters should "cluster"—that is, be more similar to one another than to the vectors of other characters.

Although there are 81 possible codes, most can be eliminated, since they never or seldom occur. Only about 28 of the codes are important, so that the pattern vectors have 28 components. The "clustering" is achieved by a mathematical process involving a kind of elementary learning known as linear separation. The process has been simulated on the Laboratory's Cambridge computer. The recognition of all upper- and lower-case Roman letters from 11 different fonts was thus achieved. Another way of stating this is that all characters of the same class but from 11 different fonts were clustered in the same region in vector space.

VISUAL PATTERN EXTRACTION: Objects in the visual field—a room, a table, a vase, a floral rug, books in a bookcase—present to the eye nothing more than light and shadow bounded by arcs, straight lines, and random geometrical curvatures. These are assembled in the brain into meaningful patterns.

For a number of years, AFCRL explored certain models which could be used to explain the process whereby the brain encodes and manipulates the complex shapes. Such models may or may not provide a better understanding of true mental processes. Just how the brain processes data is still perhaps the least understood of all physical phenomena. Nevertheless, a model may prove to be extremely useful even though it may not be valid in terms of its original intent. This is the background

The MAT technique of automatic shape description is one which transforms a two-dimensional silhouette (left) into a one-dimension line drawing (right). The computer then uses the line drawing to construct a condensed description of the original figure.

The original picture (top) is scanned and data are stored in a computer memory. From this stored data, the picture can be reproduced with reasonable fidelity (center) or it can be processed in many ways, one of which produces the edge enhanced photo at bottom.

of a computer-based pattern extraction method developed at AFCRL known as the medial axis transformation (MAT).

During the reporting period, the method emerged as a powerful new method for extracting topological features. Originally stimulated by certain properties of neural nets, such as finite speed, attenuationless propagation of information and refractory periods, the basic notion of this scheme is that of a "propagation space" into which the unknown pattern is impressed, stimulating a matrix of elements (neurons) in this space. From each element the stimulus propagates to its neighbors with a constant propagation velocity, zero attenuation, and a definite time interval during which an element, once stimulated, cannot fire again. Thus, for example, signals emanating from different locations of the input pattern tend to extinguish each other; on the other hand blemishes, such as gaps in normally continuous lines, are eliminated.

The lines along which extinction occurs as a function of time provide simplified and generalized descriptions of the input object. Complex objects and amorphous shapes that have no simple geometric descriptions—such as clouds—are transformed into a few simple lines. These "extinction" lines most often bear no resemblance to the original object. The result is a more concise representation of certain topological features. The lines of extinction which form a sort of "stick figure" of the original shape, plus the information regarding the time sequence of their formation allow a completely faithful reconstruction of the original figure. No information has been lost.

A computer program was formulated during the reporting period for making actual pattern transformations which are viewed on a conventional CRT display. The computer used is a small general purpose digital computer (Digital Equipment Corporation PDP-1), with the CRT images presented on a grid of 256 by 256 elements.

A basic advantage of the MAT method is that it provides a convenient method for describing patterns of arbitrary shapes. No geometrical constraints are placed on the pattern to be described.

Shapes in silhouette or uniform tone are processed most simply. But photographs, with any arbitrary number of grey tones can be processed by treating each grey tone as a separate silhouette.

Although the AFCRL technique appears to have high potential and at least five separate outside research groups have inaugurated research programs (non-AFCRL sponsored) to carry the MAT technique forward, a cautionary note should be inserted. In principle, it is no more economical to store the transform—that is, the stick figure—data in a computer memory than it is to store some other equally complete description of the figure. At the present stage of development, the transformed image offers only the advantage that it is in a form more suitable for computer analysis and manipulation. AFCRL scientists believe, however, that drastic reduction of storage requirements can be achieved with little—and controllable—loss of critical information.

Pattern description systems such as MAT may have a major role in the automatic processing of pictorial data. Two prime examples are reconnaissance photographs and the huge volume of cloud photographs transmitted daily to earth by weather satellites. Another important potential application of MAT is the transmission of visual data over narrow band channels. It takes more bandwidth and power to transmit complex visual patterns than to transmit simple ones. By transmitting only the transformed and simplified patterns, using the MAT technique for later inverse transformation at the receiving terminal, the technique may provide means for conserving bandwidth and power.

DYNAMIC MEASUREMENT PROCESSES: Recognition and classification is most difficult in cases where the data in question result from a dynamic process in which the data strongly interact with the environment. Dynamic measurement processing is concerned with the real time analysis of sensor data—such as visual patterns, electromagnetic signals, and acoustical phenomena—for the purpose of identifying and extracting from these data certain characteristic attributes. The data from various sensors such as radio telescopes, spectrometers, and ion gauges aboard satellites are often noisy, redundant and difficult to interpret. Interpretation itself is sometimes highly subjective. The information may have different meaning to different observers, depending on their particular point of view and their particular interest.

Research on dynamic measurement processes at AFCRL is mainly focused on the question, "What is there that is common to all sensor measurement processes?" This question serves to generalize the problem and therefore releases the analyst from the restrictive conceptualizations that are inevitable when his vision is narrowly focused on the output from a sensor of a particular type. By way of analogy, the question is concerned with the common features that might be found in the data gathered by the eye and the ear that could serve as a basis for unified analytical scheme for both sets of data.

The importance of this question arises from the growing quantity of data collected by surveillance and reconnaissance sensors of all types. A single mechanism for reducing these diverse data would be invaluable. Furthermore, the mechanism would be independent of new military sensors that continually evolve, and of the context of military operations. This requires a built-in capability for taking into account the interaction between the surveillance process and the non-cooperative medium (target plus varying atmospheric parameters) under observation.

A theory relating to the measurement and analysis of sensor data has been evolved at AFCRL. The theory is an outgrowth of a generalized algebra of measurement developed by J. Schwinger at Harvard. It is also closely related to work on general signal analysis by W. H. Huggins at Johns Hopkins, and to a theory of attribute perception by P. Greene at Chicago. Basically, it provides a mechanism for extracting minimal sets of invariant attributes from the raw measurement data. The mechanism used is derived from a small family of principles which any measurement or instrumentation procedure must satisfy. The three most important principles are: 1) reproducibility of extracted attributes, 2) mutual exclusiveness of the attributes, and 3) completeness of the set of extracted attributes.

To evaluate the relative merits of various measurement methods and different pattern recognition and property classification schemes, an extensive signal data manipulation program has been evolved. This program uses AFCRL's Experimental Dynamic Processor (the DX-1), a memory-sharing polymorphic, digital processor. This program employs the modern technique of representing each signal as a single point in an N-dimensional vector space. Initially, the coordinates describing the signal vectors may be taken as the set of measurements which serve to define the "raw" signal. The investigator is usually not interested in isolated signals, but rather in the mechanism which generates a given ensemble of "similar" signals—for example, electroencephalogram (brain wave) signal data—and how this mechanism varies from individual to individual. One may wish to know, as an additional example, the variations in the electrocardiograph data of individuals with different cardiac disorders, or differences in natural and man-made seismic disturbances. In summary, the goal of this program is to define classification procedures which do the most effective job of classifying signals that have dynamic, periodically varying properties regardless of their source or nature.

A key element of the instrumentation is a color display oscilloscope. The display shows just what any given classification scheme is doing while it is doing it. Shown are the transformations of the pattern vectors in the N-dimensional vector space. The color oscilloscope is ideally suited for exhibiting the customarily unseen intermediate results. Changes in the point of view from which the process is being observed can be made while the problem is running on the processor. The processing operation can be controlled and changed by keyboard control. Functional alterations in the structure of data filters can also be entered directly in analog form by drawing on the face of the oscilloscope with a light pencil. This mode of communication is particularly useful in obtaining a feel for the effect of certain types of perturbation on the performance of the system.

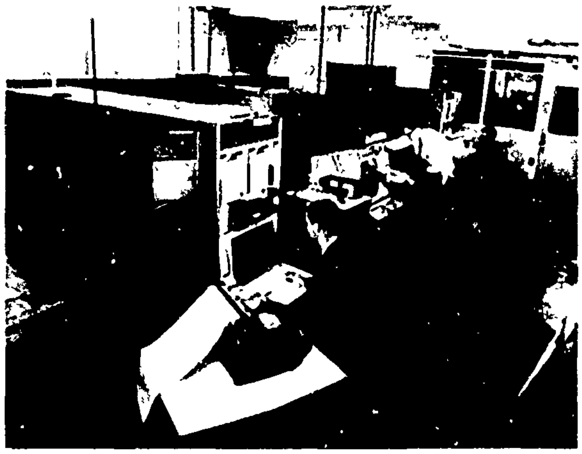
This intrinsic attribute extraction technique has been applied to the speech bandwidth compression problem (discussed in the section below) with highly encouraging results. Speech spectrogram information from the polymodal vocoder is operated on by attribute extraction procedures existing in the memory of the DX-1 System. These procedures extract certain types of invariant structures from the continuous flow of audio information and use these structures as a new, compact basis for the transmission and reconstruction of the speech signal. By this procedure, bandwidth compression by a factor of 5 with negligible effect on intelligibility was demonstrated.

COMMUNICATIONS

The research covered in this section deals with electronic communications—with techniques for transferring information more efficiently and reliably. Speech—whether in Air Force operations or in any other human endeavor—is the basic information transfer mechanism. Of the several programs of the Laboratory relating to communications, the Laboratory places the heaviest emphasis on speech research.

The speech research program has two parts. The first involves experimental equipment for the manipulation and processing of speech signals for economical, reliable and secure transmission. The best known equipment for achieving this is a class of equipments known as vocoders. The second part is more fundamental, involving basic properties of speech, the physiology of speech production, and its perception. Both parts have a common goal: to reduce the bandwidth needed to transmit speech signals from one location to another—whether by transmission lines and cables or by radio. With such bandwidth reduction, signals can be sent over greater distances (with a given amount of power), and the number of voice channels in a given circuit can be increased. Reliability and security are also enhanced.

Reduction of bandwidth required to transmit TV pictures is another communications research goal. Advantages are the same as those of speech bandwidth compression—more efficient use of channel capacity, reduced power requirements and greater reliability. Other Laboratory programs relating to communications are concerned with the encoding and transmission of digital data, and with information and communications theory. The latter is concerned with generalized communications systems. Communications theory deals with the question: What would be the minimum transmitter power, time delays, equipment complexity and so on needed to achieve an arbitrary degree of reliability, and how could these minimum values be realized in a practical operating system?



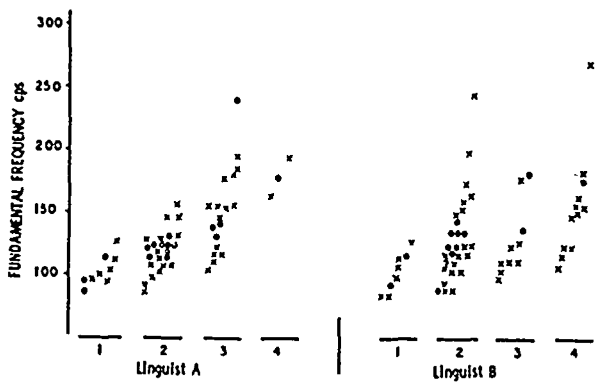
Studies of dynamic measuring processes — the real-time cooperative man-machine analysis of sensor data — are conducted using AFCRL's DX-1 computer.

MECHANISMS OF SPEECH PRODUCTION: While the goals of AFCRL's speech research program are clear-cut—the transmission of maximum information content using minimum bandwidth—the approaches are many and diverse. The purely linguistic features of speech (words, phrases, and sentences) contain only part of the message. One wishes to be able to identify the particular speaker, and one wishes to discern word stresses and emotional content. These provide the listener, often subconsciously, with a great deal of additional information, and sometimes with the essential content of the message itself.

The Laboratory is seeking a greater understanding of just how speech itself

is produced. For this research, AFCRL uses two basic facilities. One is a high-speed motion-picture camera capable of taking 10,000 frames a second; the other is a computer used to evaluate the individual frames of the resultant film strip.

Voiced components of speech are largely determined by the area of the glottal opening (the opening between the vocal cords) and the volume velocity of the air flowing through it, both as a function of time. A particular word may have voiced and unvoiced components. Pitch results from the vibration frequency of the vocal cords, and variation of pitch in voicing words, phrases, and sentences is called intonation. Intonation is an important parameter for conveying both talker identification and the emotional content of the speech signal. The AFCRL high-speed camera provides a detailed record of the physical mechanisms governing these parameters.



Much informational content of speech is contained in the listener's subjective perception of intonation. In this plot, two linguists subjectively evaluate the pitch component of two different speakers, represented by the x's and o's, who have uttered the neutral sentence, "They've bought a new car."

Using the high-speed camera photographs, the computer provides statistical, analytical data. A computer has also been used by AFCRL to simulate models of the vocal tract, and to synthesize speech under various vocal tract configurations. These studies are all related to the design of improved speech synthesizers, devices which reconstruct the sound of the original spoken message from signals that have been highly processed and modified.

INTONATION AND PERCEPTION: An effective voice communication system must be capable of conveying all the linguistically significant features of the input utterance. One such feature is intonation, the "melody" of an extended speech segment During the reporting period, a study designed to isolate and identify the purely linguistic aspects of speech from the emotional aspects of intonation and stress was completed. In this study the articulatory, acoustic, phonetic, perceptual and syntactic aspects of intonation for American English, and for such related and unrelated languages as Russian, Finnish, Japanese and Swedish were examined.

Results indicate that intonation, contrary to general assumptions, is a central linguistic feature. It is based on universal constants of human psychology and is invariant among specific language groups. A particular aspect of intonation, the "breath-groups," have particular significance in that they frequently serve to remove ambiguity from a sentence's linguistic structure. Many examples previously cited in the literature as evidence for the emotional or "attitude-conveying" aspects of intonation appear to be instances of this phenomenon. Further, the study emphasizes that, in the perception of language, the listener makes use of a feedback mechanism of the "analysis-by-synthe-

sis" type that is based on his knowledge of the grammar of the language as well as attention to the purely motor aspects of speech production.

OPTIMUM SPEECH FILTER: When the transmitter power is limited and the circuit is noisy, only parts of the spoken message may be received. Over the years a number of empirically designed limiters, clippers and filters have been used to enhance speech intelligibility under these conditions. A detailed analysis of those frequency components in speech that contribute most to intelligibility has led to an optimum, linear, time-invariant, speech processing filter that will maximize the probability of correct reception of a speech message when it is transmitted over a noisy channel by a power limited transmitter. The theory has been substantiated in a number of experiments. The filter results in an increase in intelligibility equivalent to raising the transmitter power by about 50 percent, and can be approximated by a capacitor and a pair of resistors. It will find wide use in all analog speech circuits, and as a filter to precede nonlinear circuits.

AFCRL's experience in designing filters for speech research led one AFCRL scientist to relate this work to a military problem in Vietnam, a problem which would seem to have no relationship to speech intelligibility studies. This is the problem of hearing the sound of ground fire that is ordinarily masked within the noisy environment of a helicopter or aircraft. Early detection of small arms fire from the ground could give the pilot the opportunity to take evasive action. The AFCRL researcher saw the problem as fundamentally a filter problem. With proper filtering, the frequency components of the aircraft engine could be suppressed and those of small arms fire from the ground detected and amplified.

Extended beneath the nose of the helicopter is an acoustic warning device to be used in Vietnam for warning pilots of ground fire. Elements of this simple device are shown in detail in the lower photograph.

This led to the design and development of a simple ground fire detection system which is being tested in Vietnam on both helicopters and on Navy gunboats in the Mekong delta region.

The system consists of two microphones placed on opposite sides of an artificial "head" with the spacing between the microphones being roughly that separating the two ears. Their out-

puts are fed, binaurally, to the pilot's ears through amplifiers that have high-pass filters with a cutoff at 3.5 kHz. The filters cut out much of the low frequency noise from the helicopter or light aircraft without reducing the noise of the ground fire. The signal-to-noise ratio is increased by about 30 db. The two separate microphone channels provide the pilot with directional information, telling him the location of the ground fire.

In tests with helicopters and liaison aircraft the position of a 7.62 mm machine gun firing short bursts of live ammunition could be located from a helicopter at altitudes ranging from 100 to 750 feet and at distances to 500 yards during normal combat maneuvers. The detection system is rugged, self-powered and uncomplicated. Its electronic components can be miniaturized to less than 10 cubic inches, and the system can be produced at a cost in the order of $100 per unit.

At this console, much of AFCRL's research program in speech bandwidth compression is conducted. Associated with the console are several vocoder equipments.

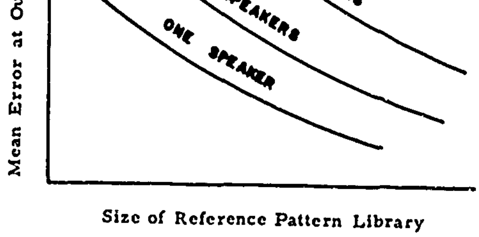
SPEECH PROCESSING: Speech processing entails the filtering, encoding and digitizing of speech signals into more electronically manageable and efficient units for transmission. At the receiving terminal the transformed signals are reconstructed for acoustical reproduction by a voice synthesizer. This processing is carried out to achieve a compression in the bandwidth needed to transmit the message. For example, the bandwidth used to carry an ordinary telephone message is about 3000 Hz. With speech processing techniques, the same message can be carried by a bandwidth of less than 600 Hz, which means that a given transmission line (or radio frequency band) can carry five or more messages instead of one.

Most research in speech processing is focused on vocoders, equipments which perform two basic operations. They filter and thus separate the various frequency components of the basic speech signal, and they convert the signal to digital form for more efficient transmission. AFCRL scientists have concentrated on a class of vocoders known as channel vocoders. Channel vocoders presently have advanced to the point where they provide highly intelligible speech and useful speech compression factors, but require further improvements in voice quality and naturalness. During the reporting period, the Laboratory has reduced—but not eliminated—the metallic, mechanical quality of the sound produced by channel vocoders.

In a limited way, vocoders have, within the past few years, been introduced into operational systems. But for many operational situations, special problems still exist. One of these is the use of these equipments in a noisy envi-

ronment—in an aircraft, for example. Another is their use for conference communications where three or more telephones are patched together for conference discussions. In this situation, the output from one or several vocoders must serve as the input to another. Input signals in both cases are not suitable for conventional vocoder processing. During the reporting period, AFCRL gave special attention to these two problems. Improvements, but no definitive solutions, were achieved.

SPEECH PATTERN MATCHING: Pattern matching is self-descriptive. A pattern is compared to a set of "standard" reference patterns. When a complex speech waveform matches well with a reference waveform, it then becomes possible to transmit only a relatively simple code or number which at the receiving terminal is used to locate the speech waveform from a duplicate set of reference patterns. Matching is done automatically by a computer. This approach to



Errors are minimum when the system is called upon to deal with the speech patterns of a single speaker and when the reference library is large.

speech bandwidth compression originated at AFCRL. Investigations have shown that because a logarithmic relationship exists between the number of reference patterns and the information transmission rate associated with transmitting speech by this method, it is possible to accommodate a repertoire of many thousands of voice patterns. Distinguishing characteristics of different speakers—manner of speaking, enunciation, regional dialect and so on—can be preserved, to a degree, even at very low data rates. Rates much lower than those required by conventional channel vocoders are possible.

During 1966, a milestone was reached in this research. A new and fundamental relationship in pattern matching was established. The significance of this relationship may extend beyond the narrow limits of speech pattern matching into the more general area of pattern recognition.

A basic difficulty in the speech pattern-matching scheme to speech compression has been the intrinsic variability of the speech of a particular speaker, and in the different parts of speech sounds. Consonant sounds have a smaller variability than vowel sounds; monosyllables are less variable than connected speech. AFCRL has established that voice pattern matching can be described mathematically by a tradeoff function. The function predicts the average spectrum error (in a spectrum pattern-matching process) in relation to the number of reference spectrum patterns stored in the memory of the processor, and a coefficient reflecting the intrinsic variability of a particular speaker.

With the basic formula, it is possible to estimate how many patterns will be required in a processor in order to describe a particular speech sound to any degree of fidelity. The formula has been

given the name, "Genetic Operating Characteristic," or GOC function. It was shown that the average spectrum error is highly correlated with speech intelligibility scores obtained with the use of listener crews.

Since the number of reference patterns is closely related to the data rate requirement, the tradeoff equation permits a direct estimate of the information in bits required in order to obtain any required speech intelligibility level, for a speaker for whom the variability coefficient is known.

These studies have established a firm basis for an exact characterization of a speech pattern-matching process, and have sharply focused the key questions still requiring solutions. Research will now center on establishing the range of variability of different speakers, and on establishing the reliability of performance estimates obtained with the use of the GOC functions.

NARROW-BAND TELEVISION: Techniques for transmitting black-and-white television pictures over narrow bandwidths have been investigated at AFCRL since 1963. With techniques developed by AFCRL, bandwidth reduction to about 160 kHz are possible. This compares with a bandwidth of four MHz for commercial television. The technique depends upon the integrative properties of the human visual system.

Under this program, AFCRL has demonstrated that reduced bandwidth pictures can be achieved at slower transmission rates by the pointwriting of the picture. Pointwriting contrasts with the familiar line scan used to reproduce the conventional TV pictures. The points of light which make up the final picture are presented at different areas on the screen in a pseudo-random manner. Bandwidth reduction can be accomplished with no picture degradation provided the bandwidth reduction factor is not too large (perhaps up to 25). At rates too low, picture quality, of course, deteriorates rapidly.

The definition of picture quality is ultimately subjective. Part of the research has psychological research overtones and takes place in a viewing room in which test subjects give subjective evaluations of picture quality. Here various types of scans are generated under conditions of controlled brightness, contrast, resolution, and frame rate. Flicker fusion, motion resolution, effects of phosphor persistence, grey level fusion, and figure detection in pictures of drastically reduced point writing are evaluated.

In one picture evaluation experiment, a uniform field containing a dark rectangle in motion is presented. Frame periods (the time taken to write all

With AFCRL's pointwriting technique, TV bandwidth reduction of 25 to 1 is possible. Bandwidth reduction of 5 to 1 without picture degradation has been demonstrated.

points in the picture raster) were varied from 1/60 second to six seconds. The object is to see the rectangle. If the contrast between the rectangle and the background is low, a fairly high point rate is required for perception. However, as the contrast is increased, the rate may be decreased to achieve the same perception probability, until in the extreme of black or white the rectangle can still be perceived at a six second frame rate, even though the viewer is exposed to the picture for only one second. Thus, the subject discerns the picture even though more than 80 percent of the pseudo-randomly generated points that make up the total picture are not seen at all.

It appears from this result that perception of the boundary of the rectangle is due to the contrast between the interior and exterior. This supports the contention that the human visual system integrates light in both space and time and that short integration times or marginally different objective contrasts result in a gradual decrease of subjective contrast.

A demonstration of the television system has been breadboarded. Made with standard off-the-shelf components, this system is capable of a bandwidth reduction of four or five without degradation. The surprising prediction that good motion resolution could be achieved with low (2–5 frames per second) frame rates has been clearly demonstrated. Follow-on investigations will attempt to determine optimum phosphor persistence times for low frame-rate television using a variable-memory storage tube to simulate the phosphor. It is anticipated that decay times around 1/10 second will be desirable, a value very difficult to achieve with current phosphors.

Among the equipments used by AFCRL in this research are a video magnetic tape recorder and television cameras. Capability also exists for generating high quality pictures from a noisy input by integration in a storage tube. The investigations make extensive use of a small-scale, high-speed computer (PDP-1), and peripheral equipments.

ANALOG TRANSMISSION: All large Air Force electronic systems—for air defense, for routine communications, or for the telemetry of satellite data—involve the transmission of coded signals. The channels over which the information is transmitted are all less than perfect. Through the application of information theory to communications problems and the tradeoffs that theory prescribes, it is possible to obtain a specified high reliability even over badly degraded channels. The objective is to achieve this high reliability with a minimum of time delay and equipment complexity. This applies to both analog and digital transmissions.

Pulse code modulation (PCM) has long been used as a method of digitally transmitting analog signals. In this method of transmission, the analog waveform is sampled, or measured, many times each second, and the value of each sample is then transmitted digitally. It has been recognized for some time that the value of the sample at a given time is strongly constrained by the values which precede and follow it. This would make it possible in principle, to transmit the waveform with a smaller number of bits per second than that dictated by the product of the number of samples per second and the number of bits used to represent each sample.

In showing that this method of transmitting analog data is near-optimum under an extremely wide range of conditions, a major advance in the theory of analog transmission has been made by AFCRL. Specifically, it has been

This encoder-decoder was developed by AFCRL to simulate noisy channels, permitting researchers to evaluate the effectiveness of various error correcting codes.

shown that uniform quantizing together with entropy-reducing coding is the optimum method of PCM transmission when small error is required, independent of the statistics of the source of the waveform, and independent of the error criteria used. Furthermore, it has been shown, in conjunction with the work of AFCRL contractors, that this method yields a performance close to the best attainable with any method of transmission of analog data.

Concurrent with theoretical studies of basic limitations in transmissions of analog waveforms, AFCRL is investigating practical methods of achieving the theoretical limits. One promising avenue currently under investigation consists of various prediction and difference transmission schemes in which both the transmitter and the receiver predict the value of the next sample so that only the difference between the predicted value and the actual value need to be transmitted. Both linear and nonlinear predictors for this purpose are being studied.

ERROR CORRECTING CODES: Error correcting codes are a proven method of attaining reliability of digital transmissions on a channel subject to errors. One property of an error correcting code which is useful for describing its capabilities is its minimum distance, which is the smallest number of digits in which code words disagree. This number is important because it is certain that the code can correct any pattern of errors having a number of errors less than one-half of the minimum distance. It has long been known that at any specific code rate and code length there exists a certain value of minimum distance which can be attained by at least one from the millions of possible codes of that rate and length. The search for such a code has seemed fruitless in some part owing to the needle-in-the-haystack type of search involved. AFCRL has shown that, in fact, not just one code has this desirably large minimum distance but that nearly any code selected at random does. The problem thus has been changed from that of finding the one good code to that of finding the most easily instrumented code of a very large class.

Three approaches to the construction of useful coder-decoder combinations are being investigated by the Laboratory and its contractors. The first of these is an intensive study of the weight distribution of specific codes and of the algebraic structure of these codes. This information permits selection of the optimum code for a given application and provides a guide-line to the easiest instrumentation of it.

The second involves the construction of an AFCRL designed coder-decoder

for use in feedback communication systems involving null zone detection and request for repeats. In addition to being a practical coder-decoder in its own right, this unit offers the flexibility for testing various system configurations using fail-safe decoding.

The third approach uses a hybrid detection-coding scheme in which the separate roles of matched-filter detection of the individual bits and error-correction of the resulting bit stream are coalesced into the single operation of match-filter detection of the whole collection of code words. The method is particularly effective with short codes.

The development of more effective computer languages requires close cooperation between the operator and the machine.

COMPUTER LANGUAGES AND PROGRAMS

This section deals with methods for communicating more effectively with computers. With better communications, existing computers could perform many more tasks than they are now assigned —and could carry them out with far fewer instructions. What is sought is closer and more natural interaction between man and machine. In this respect, two related lines of inquiry are being pursued by AFCRL.

One of these is the design of user-oriented (as against machine-oriented) programming languages that will permit the user to outline his program for machine computation in a natural language—a sufficiently concise version of English, for example. This is an ambitious goal, and far distant. Less ambitious is the design of an artificial language that approximates the way the user would describe his problem in natural language. In either case, the user is made less dependent on the conventional machine programmer, who must take the problem and break it down into a set of step-by-step procedures.

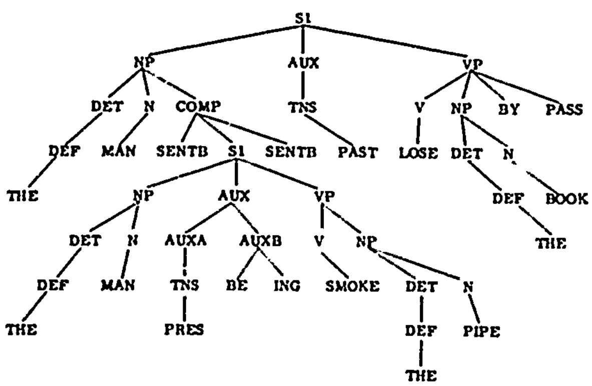
The second approach to improved man-machine interaction is one whereby the user can intervene during the computational process to instruct the computer to perform certain operations—an approach known as on-line use of computers. This close interaction between man and machine results in a cooperative effort in which the special talents of both man and machine are brought to bear on a particular problem.

LANGUAGES IN PERSPECTIVE: This will be a brief tutorial discussion inserted to provide background information which may make the later presentation of the Laboratory's work on computer programming and languages more meaningful. Comprehension of this technically abstruse area tends to elude the non-specialist.

All internal information in a computer is couched in abstract machine

code that has no direct relation to the problem the machine is working on. This is why the programmer is needed to serve as translator. To reduce the dependence on conventional programmers and to facilitate communication between user and machine, "problem-oriented" and "procedure-oriented" languages have been created. Among these are COBOL, LISP, FORTRAN, and so on. These artificial languages make it possible for the user to state his problem and specify the desired procedure to the machine in a form related as close as possible to the form in which he would naturally state the problem.

Programs written in such a language must nevertheless be translated into the internal language of the particular type of machine on which they are to run. This translation is done by compiler programs. One instruction in the procedure-oriented language usually implies a large number of individual computer instructions which are automatically detailed in the compiling process. Eliminated are the tedious housekeeping tasks which must be explicitly spelled out when a conventional machine-oriented program is used.



There are many possible trees for analyzing the natural language sentence, "The book was lost by the man that is smoking the pipe," using the LISP S-expression notation as the input format. Defining rules for programming in a natural language taxes the ingenuity of the logician.

Procedure-oriented languages used to converse with machines are still remote from ordinary conversation. Furthermore, there are many languages for many different machines. The goal of present research in programming languages is to make languages more universally applicable. Also needed are efficient means of translation from various languages into compiler programs as well as from one language to the other.

This has led to intensive research on the syntax and grammar of both artificial and natural language. Such questions as equivalence of statements in different languages, translatability and relative efficiency, and effective ways of syntactic analysis are in the foreground of present research.

GRAMMARS AND COMPILERS: It was seen in the foregoing discussion that procedure-oriented artificial languages must be translated into a form that is acceptable to a particular computer, and that such translation requires compilers. A compiler is usually designed for a particular type of computer and a particular language.

If the same language is to be used with another machine, a special compiler for the second machine must be used, since a compiler developed for one machine cannot usually be used with another. The development of a compiler program is a task of large proportions—and costly.

Ideally, one would wish to be able to program any machine in any procedure-oriented language one chooses—that is, any given language should be freely translatable into any needed machine codes. By separating those components that are common to all translations be-

tween any source-target language pairs, and those that are peculiar to a specific pair—that is, the syntactic and lexical descriptions of the languages in question—one arrives at so-called syntax-directed compilers. These compilers are adaptable to large classes of source-target language pairs with much less effort than it would take to construct special purpose compilers. AFCRL has made outstanding contributions toward the efficient and economical implementation of this type of compiler.

Work in the Data Sciences Laboratory is directed toward the analysis of the rules of formulation (grammars) and the structural similarities of the various source languages—English as well as the artificial languages. Specifically, AFCRL work centers on the following problems: 1) What type of grammar is appropriate to define particular languages? 2) What are the theoretical properties of the various types of grammars that are of practical significance? 3) What procedures can be found for efficiently determining the structural description of a language with respect to a grammar of a certain type? and 4) How can the structural descriptions be mapped into equivalent machine code programs?

TRANSFORMATIONAL GRAMMARS: Transformational grammars is the term used for the process of assigning structural descriptions that reflect each of the possible meanings or interpretations of a sentence. In order to use a transformational grammar, it is necessary to have a procedure for finding all possible structural descriptions of a sentence. Transformational grammar, a field to which AFCRL has made significant contributions, is the best descriptor of natural languages, such as English, that has been proposed to date. This work is leading to less and less restricted subsets of English as possible programming languages, and may lead to the direct use of a formal, stylized English in programming computers.

AFCRL's logic network studies are largely conducted using the Cambridge computer, a computer installed at AFCRL in 1955.

The Laboratory has developed a computer program for finding all possible structural descriptions of a sentence which is the first mechanization of such a procedure to have been developed. This program is written in the LISP programming language; versions have been produced for the IBM 7094, the AFCRL UNIVAC M-460, the DEC PDP-1, and the MIT CTSS systems. The program diagrams a given sentence in all possible ways consistent with distinct meanings. The procedure is not only valid for the transformational grammar of a particular natural language but is also equally applicable to any transformational grammar satisfying certain conditions. Although in its present form it is too slow to permit practical use in an information processing system, the program is useful to linguists engaged in writing and investigating large transformational grammars.

Using the AFCRL syntactic analysis program several transformational grammars of subsets of English have been debugged. The largest of these was written by investigators at the IBM Watson Research Laboratories and modified and tested at Brandeis on the MIT CTSS System. AFCRL has initiated a program of semantic interpretation of the deep and underlying structures of English which can be translated to appropriate LISP functions.

In general, transformational grammars provide the basis for an adequate semantic interpretation with a minimum of ambiguity and grammatical rules. They provide one of the most promising approaches to more natural communication with a computer.

ON-LINE USE OF COMPUTERS: For certain kinds of problems, the optimum situation is one in which the computer and the user jointly bring to bear their respective talents in seeking a solution. In this situation there is close interaction between the computer and the user at various stages of the problem-solving process. Such on-line use of computers requires special programming languages for easy discourse with the machine. The user must have means to specify his suggested approaches to the computer, and the computer must display the results of its own efforts in a suitable form at interim stages during the processing.

A special programming language was developed as a vehicle for the study of the design, implementation, and use of on-line systems. AFCRL's M-460 computer has been used in all of this work. An assembly-language programming and operating system for the computer, oriented completely toward on-line use, was constructed. This contains a macro-assembler, editing program, and a flexowriter-controlled debugging program permitting examination and change of programs in assembly language, insertion of program breakpoints, and various other features. Building on this debugging program, a more elaborate assembly-language debugging program with quite novel features was later developed. It permits insertions into or deletions from the program being debugged with appropriate relocation of the remainder of the program.

In the area of higher-level languages for communications between user and machine, a complete version of the LISP programming language with debugging features especially designed for on-line use, such as break-points and more selective tracing, was implemented on the M-460 computer. The transformational grammar mentioned above was developed using this LISP system and was debugged far more rapidly than would have been possible with conventional methods.

An example of a program in which user interaction is essential is one using LISP to test a context-free grammar and the associated translation rules. The grammar and these translation rules together make up the tables for a syntax-directed compiler. The program permits the user to apply his syntax and translation rules to test certain cases. Working closely with the computer, the user can examine the results, modify the syntax and translation rules, test them again, ask the computer to examine special cases and so on, until he has arrived at a satisfactory result. The convenience and economy of this procedure is in striking contrast to conventional procedures.

THEOREM-PROVING: The foregoing was concerned with general aspects of computer languages and programming. The Laboratory also formulates special computer programs for a wide variety of specific purposes. One such program

deals with theorem-proving. Proving theorems in some well defined theory is an intellectual, even creative task. Where theorem-proving is performed by a machine, the machine may be said to exhibit artificial intelligence. Nevertheless, a prior condition to this performance is the development of an effective program.

A theorem-proving program can be used to make deductions about some body of information which is supplied to it in the form of axioms. The mobility of a commander's force, for example, could be expressed as a set of suitable axioms, from which could be deduced whether a particular deployment could be reached within a given time period. Additional axioms expressing the enemy's capabilities could be used to include the effect of his hostile action on the possibility of reaching the desired force disposition. In this kind of system the complexities can always be increased by providing more axioms. Such a system is conceivable, but not yet practical.

One AFCRL theorem-proving program is a proof procedure for first order logic descended from the programs of Davis and Putnam and J. A. Robinson. It uses Robinson's resolution principle as the basic rule of inference. The program concentrates on preventing the generation of equivalent partial proofs in order to reduce the rate of exponential increase of the number of partial proofs as a function of the number of resolution steps applied to the original theorem. One particularly effective technique has been found which depends on a sort of associativity enjoyed by resolution which makes the order of application of resolutions in a partial proof irrelevant.

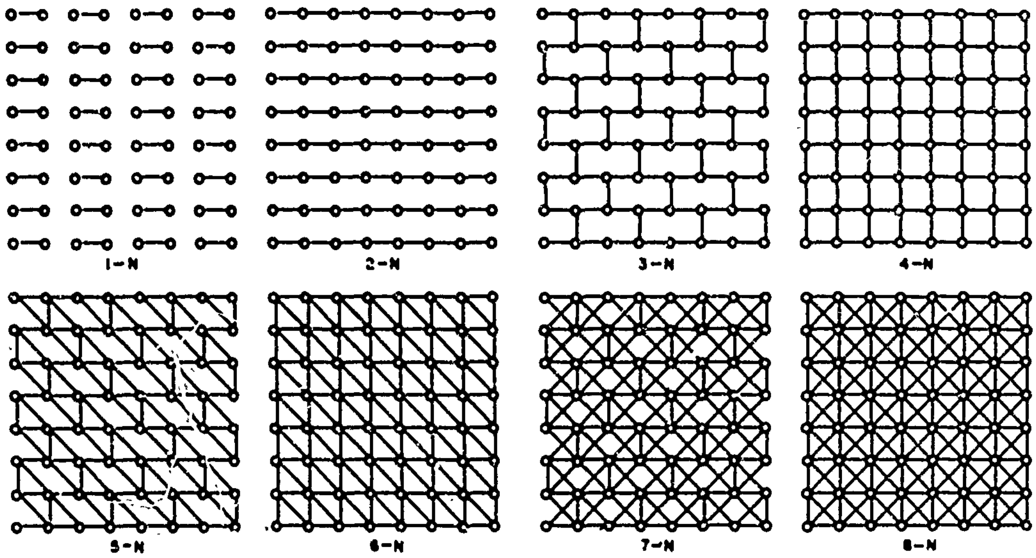
This program is also capable of handling the notions of equality and commutativity and associativity of functions not explicitly axiomatized. This results in some additional improvement in efficiency since axiomatizations of these concepts invariably lead to duplicate lines of proof being developed. This program has proved theorems which are considered difficult by humans.

LOGIC NETWORKS AND CIRCUITS

Integrated circuit technology has brought radical changes in the design and construction of computers. The computer industry has set a trend toward the integration of more and more complex functions on one circuit chip that contains hundreds or even thousands of components. This trend, while promising to lead to computers of vastly improved capabilities, has also created new problems. These require systematic exploration.

For example, assuming that a maximum number of functions per chip is in fact desirable, what functions should be integrated into the chip? One aspect of this question is the problem of the "circuit-to-pin" ratio, since only a limited number of conductors leading to the outside world can be attached to any given chip. Another problem has to do with standardization. Because a near-infinite number of circuit designs can be fabricated, efficiency dictates the need to restrict the inventory of different integrated chips required to build a machine. Custom designed chips produced in small numbers are prohibitively expensive, while chips, even very complex ones, become quite inexpensive, if produced in large quantities. On the other hand, the more complex the function of a chip, the more specialized it becomes unless special measures are taken to lend functional flexibility to the chip without physical change.

Further problems are: reliability of arrays consisting of less than perfect



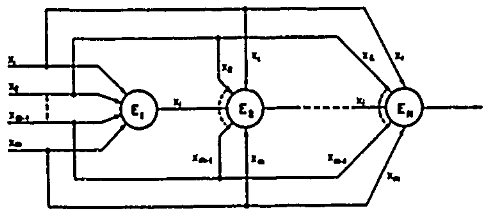
In logic nets, an element may connect to one or to many neighbors. Interconnection patterns in which elements are connected to one through eight neighbors provide simple and straightforward geometries.

elements; the sequential behavior of such arrays due to the finite switching speed of the constituent elements; the restrictions of the chip geometry that suggests that preferably only elements located in a common neighborhood communicate with each other, and finally, the adaptation of electronic techniques to satisfy the requirements and constraints of the above conditions.

AFCRL programs in logical networks cover various aspects of all of these problem areas.

POLYFUNCTIONAL NETS: In the introductory remarks above, the terms "logic network" and "elements" were used. A logic network is a set of logic elements interconnected in a certain way. The elements are assumed to be structurally identical in keeping with efficient integrated circuit technology. If the interconnection pattern is subject to certain geometrical constraints, as is the case in many practical applications, the term logic array may be used.

The logic elements constituting the network are smaller circuit configurations capable of performing one, or a set of, logic functions of limited complexity. The overall function of a network is thus determined by the connection pattern, the functions performed by the individual elements, and, in an important class of networks, by additional control inputs to the network. Nets that can perform many functions depending on the set of functions assigned to its constituent elements are called polyfunctional nets. These nets have been extensively investigated at AFCRL. The work is dominated by two basic questions. Given an arbitrarily large net, what is its overall function



Logic network research consists of the development and analysis of optimum net structures. A polyfunctional net with multiple inputs and a single output is shown here.

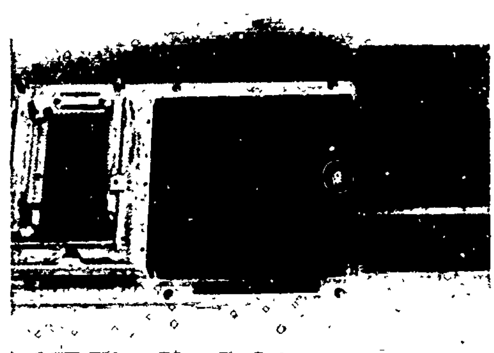
set under all possible sets of function assignments to the individual elements? What happens to the overall set of functions if the net is composed of unreliable components?

During the reporting period, work continued on iterated homogeneous polyfunctional nets of the type described in the previous report. These are nets which "grow" from an initial array of elements having the same number of inputs and outputs as the individual element. Each element is replaced by a replica of the whole array, and in the new array each element is again replaced by a larger array, a process of iteration that can be repeated any number of times. It has been shown at AFCRL that, under certain conditions, this scheme permits the design of circuits with any specified degree of reliability, depending on the number of iterations—that is, the amount of redundancy.

Extension of this research during the present reporting period aims at relating net structure to net function. New parameters, which measure important properties of polyfunctional nets have been defined and a host of difficult problems regarding these parameters have been formulated and published in the paper entitled "Structure and Function in Polyfunctional Nets."

SEQUENTIAL BEHAVIOR OF NETS: Each network element requires a finite time to react to an input signal. Due to this switching delay, signals propagate through the network at finite speeds. This property is an important factor in the design of logic nets. A study was undertaken to determine the theoretical limitations of sequential or history dependent digital networks constructed from a large number of identical elements, in particular of the input-free behavior of an array of arbitrarily interconnected NOR elements each containing one unit of clocked delay. The NOR element was chosen because of its widespread usage in digital computers.

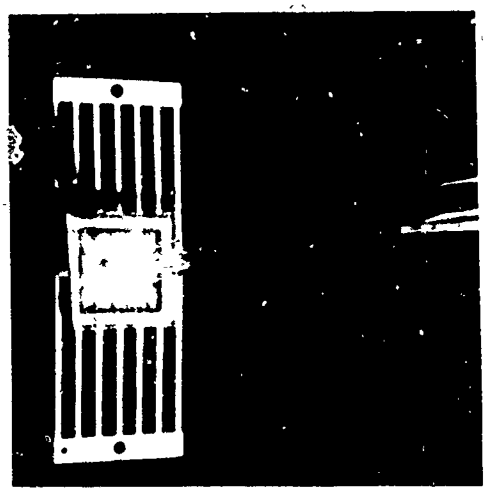
Results to date include the discovery of necessary and sufficient conditions for networks to produce certain special behavior patterns (such as cycles and "rooted tree" state sequences) and the establishment of computational methods for determining the stable states for certain regular networks. These have

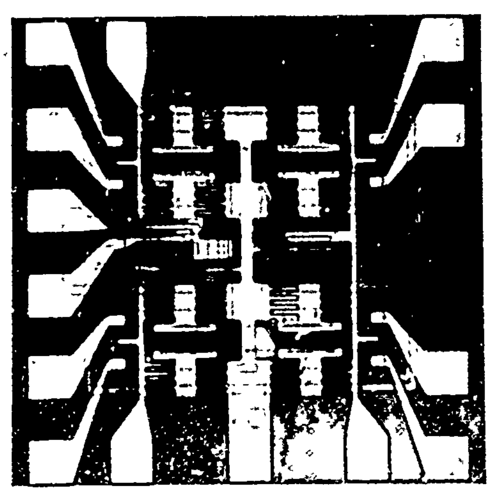


Light shining through slots in an IBM card inserted in the holder at left activates photosensitive switches to specify connections between elements in this 120-node eight-neighbor array.

special importance in that they determine the storage capability of the network and can serve as basis of comparison of these networks with more conventional computer networks.

CIRCUIT THEORY: When a circuit has been designed to carry out a particular function, how does the designer know that his design is the best in terms of simplicity, economy, space and weight? He doesn't. To perform a given function, a great variety of circuits can be constructed. There are few guidelines to tell the designer that his circuit is optimum. Circuit theory deals with this matter.





Fiberglas threads conduct light to photosensitive surfaces to connect and disconnect parts of the element, thereby changing its function. The polyfunctional element without thread attachments is illustrated below.

Circuits consist of resistive, inductive and capacitive components associated with active semiconductor devices. Different circuits are, of course, built to perform different functions—filters, phase shifters, delay lines, feedback stages and control devices. Of the many possible ways to design a circuit for a given function, the particular application may impose special requirements. Military requirements are particularly stringent. In some operations, ruggedness may be a dominant criterion; in others, minimum weight and space; in still others, maximum reliability.

Research at AFCRL is concentrated on finding objective methods for selecting the optimum circuit to fill a particular requirement and for making this selection as simple as possible. The approach is to express the desired network behavior mathematically. Analysis and classification of this formulation subsequently makes it possible to enumerate all circuits having desired characteristics. Another study involves computer-aided design procedures starting with the basic function formulation and ending with the completely designed network structure. For this purpose, many operations of numerical analysis have to be modified and programmed; a language suitable for technical network design has to be developed and some difficulties arising from inaccuracies by trunkated computation have to be overcome.

Results of one AFCRL study were published in a major two-volume report during the period, "Categorizations

and Realizations of Positive Real and Biquadratic Immittance Functions" (AFCRL-66-243 and AFCRL-66-243 II). In this study, it was shown that a positive real immittance function F(s) is of one of eight categories. The category can be recognized by the sign polarities of three test values that are functions of the coefficients of F(s). If F(s) is of a certain category, then the immittance function can be realized in three different ways: 1) by an RC or an RL network with positive elements, 2) by an RLC network with exclusively positive elements and an equivalent model circuit, or 3) only by model circuits. A model circuit is an RLC ladder structure with one negative branch element. The RC, RL, RLC, and model circuits in turn all have several equivalences.

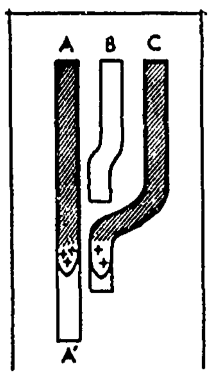
DOMAIN TIP LOGIC DEVICES: The research covered thus far in this Chapter is work conducted in-house by AFCRL scientists. Space limitations preclude discussion of the full range of the Laboratory's contract program. Particularly noteworthy, however, is a research result by an AFCRL contractor, the Laboratory for Electronics, representing a basically new departure in logic devices. These devices are based on the interaction between controlled domain walls in thin magnetic films. This interaction occurs when the magnetization of the film is reversed.

These magnetic thin-film devices are called domain-tip propagation logic devices. The devices consist of an aluminized glass substrate onto which is deposited a thin-film (0.1 micron) nickel-iron-cobalt alloy. Before deposition of the alloy, very thin (3 mil wide) lines or channels are etched into the aluminized substrate. Small regions of magnetization called domain tips, are nucleated at the ends of the channels. Under the influence of an external field, these regions propagate along the channels, providing that their progress is not inhibited by mutual interaction between domain tips in adjacent channels. In this manner, logic gating functions can be performed. For example, in the etched zigzag pattern that operates as a shift register domain tips located at the corners of the pattern representing "ones" propagate along the pattern under the influence of the external shifting field. Shifting in both directions is possible.

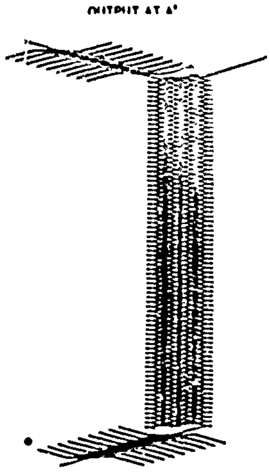
Depending on the channel geometry, a variety of logic elements can be fabricated. Domain tip logic devices can serve as list memories, buffers, scalers, counters and arithmetic units. Compared to transistor elements, they can be operated with comparable power, are more reliable, particularly under severe shock and radiation, and are more economical to fabricate. They can also be packaged with very high densities.

This AFCRL-sponsored technique is under consideration by the Army's Harry Diamond Laboratories as a highly reliable fuse timer for detonating explosive projectiles. In this application, the devices count the lapse of time by stepping the small regions of magnetization along a zigzag channel. The timer can operate in a temperature range of —40 to +60 degrees C while spinning at 35,000 rpm following the 30,000 G shock of firing.

OTHER CONTRACTOR PROGRAMS: If a given array were versatile enough to perform many functions, great economies could result from quantity production of standardized arrays. One way of achieving this versatility with fixed-function elements is to change the pattern of interconnections between elements. In doing so, one can change the array functions.



A LOGIC NOR GATE
INPUT AT C BLOCKS
OUTPUT AT A'



A simple NOR gate using the domain tip propagation is shown above. Below is a more complex etched configurat .. for a 300-stage shift register.

For several years AFCRL and its contractors have worked on a technique whereby interconnections are controlled by incorporating light-sensitive components in each element. Each element can be connected to its neighbors or disconnected by means of the absence or presence of light. In this manner, the function of the array can be altered by projecting different light pat' ns on it. To study the behavior of suc vorks, a model consisting of 120 ND cells was built in-house from commercial integrated circuits. A large variety of data processing subassemblies were imbedded in this array—for example, binary counters, complex sequence generators, decoders. Each function is realized by a separate IBM card with appropriate patterns of punched holes through which light passes to impinge on selected light-sensitive elements.

During the period, RCA under Laboratory contract announced a new semiconductor thin-film transistor technique using N and P type MOS transistors in complementary symmetry arrangement. The transistors are made in a thin silicon film deposited on a sapphire substrate. The circuits operate at a very low power level of about 7 microwatts with switching times in the order of a few nanoseconds. They can be connected in large arrays for both storage and logical operations.

An experimental memory employing these circuits and capable of storing nine bits of computer information was built. Similar memories capable of storing up to 4,096 bits and of processing them at a rate of 20 million bits per second are feasible.

Their most promising application is as scratch-pad memory for computers. Scratch-pad or auxiliary memories are needed to bridge the growing discrepancy in speed between the main computer memory and the logic circuits which process the information in a computer.

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III Space Physics Laboratory

The Space Physics Laboratory conducts research in solar, stellar, lunar and planetary astronomy, and on the fields and particles in near and deep space. The research program of the Laboratory encompasses studies of the earth's radiation belts, cosmic rays, the magnetosphere, and meteorites. Astrophysics research provides a unifying theoretical foundation for much of the observational program. In addition to space-oriented, observational and theoretical studies, the Laboratory conducts energetics research directed toward finding better ways to generate electric power for space operations and to convert energy from one form to another.

The research program is designed to learn more about space phenomena that might affect Air Force ground, airborne and space systems. A basic goal of these investigations is to develop techniques for predicting changes in the near space environment. This goal led the Laboratory to undertake in 1964 a large program for forecasting the onset of high-intensity proton fluxes from the sun, magnetic disturbances which affect Air Force communications and detection systems, and variations in the airglow and auroral activity. The Laboratory works closely with the Air Weather Service in this program, with 17 AWS officers and airmen being assigned to the Laboratory for work relating to space forecasting.

The Laboratory operates two major U. S. observatories. These are the Sacramento Peak Solar Observatory at Sunspot, New Mexico, and the Sagamore Hill Radio Observatory at Hamilton, Massachusetts. In addition, the Labo-

ratory operates a small lunar observatory (24-inch telescope) at Concord, Massachusetts. Jointly with the National Science Foundation, the Laboratory has sponsored and funded the Cerro Tololo Inter-American Observatory in Chile, a project which began in 1960. This observatory, to be managed by a group of American universities and Chilian astronomers, became operational in 1967. The 60-inch telescope is the first telescope designed to have image resolution of 0.5 second of arc over the very large field diameter of 1.5 degrees.

In addition to its astronomical instruments, the Laboratory operates two large shock-tubes for plasma physics and astrophysics research, and has three vacuum chambers for simulating the lunar environment. The Laboratory instruments a large number of rockets and satellites each year. During the reporting period, 26 different experiments were carried aboard 16 different satellites. Laboratory scientists also instrumented 11 rockets.

SACRAMENTO PEAK OBSERVATORY

Since 1952, when it began operations, the Sacramento Peak Observatory has become one of the most productive solar observatories in the world. With the addition of a new 335-foot vacuum tower telescope (construction began in 1966 with operations scheduled to begin in 1968), the capabilities of the Observatory will be excelled by few solar observatories anywhere. The 9000-foot peak in Sunspot, New Mexico, on which the Observatory is located, provides an excellent "seeing" location. Astronomers at the Observatory conduct a variety of research programs ranging from routine, continuous monitoring of the sun to theoretical studies of phenomena on the sun's visible surface and in its atmosphere.

At Sacramento Peak, there are two observatory domes, each with a number of telescopes mounted on a common spar. In the smaller of the two domes are: 1) a 6 cm flare patrol telescope, used to observe flares and other types of activity on the solar disk, 2) a 10 cm spectrocoronagraph for taking spectra of the corona at all positions around the sun's limb, and 3) a 15 cm coronagraph that artificially eclipses the sun so that activity such as the corona, prominences, and spicules on the limb can be observed, and 4) a conventional 16 cm white light telescope that photographs the whole solar disk for monitoring sunspot evolution. Each of these telescopes is equipped with time-lapse photographic equipment, so that the recorded observations can be played back to show the solar activity greatly accelerated.

In the larger of the two domes are a 16-inch coronagraph, a 15-inch chromosphere cine telescope, a 16-inch telescope for observing the sun's magnetic fields, and a 9-inch photoelectric coronagraph. During the past two years, several improvements in this instrumentation were made. The most important addition is a universal spectrograph for use with the 16-inch coronagraph, built and installed in-house. It photographs the spectrum with medium dispersion from 3200–9000 angstroms in two exposures.

THE SUN, GENERAL FEATURES: The sun, the object of study by Sacramento Peak astronomers, has a diameter of 1.4 million km. At the sun's core a temperature of 14 million degrees K is maintained by a continuous thermonuclear reaction. At the bottom of the photosphere—a layer 300 km thick—where

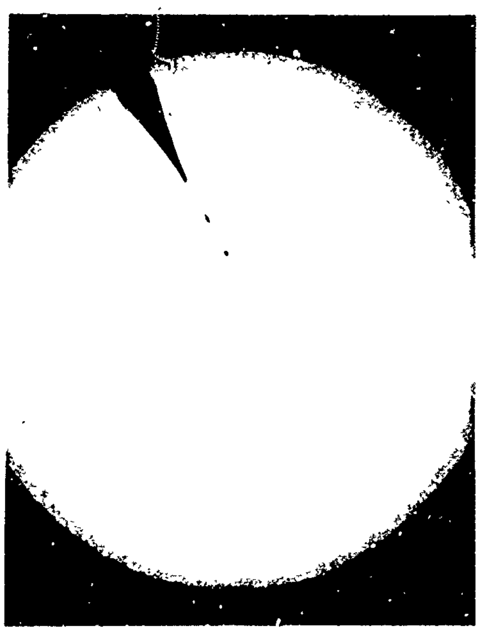
The Sacramento Peak Observatory is located on a 9000-foot peak near Alamagordo, New Mexico. Construction site of the new vacuum telescope is seen in the upper left of the picture.

the sun's visible surface begins, the temperature has decreased to 7000 degrees K and further decreases until it reaches a minimum of 4500 degrees K at the top of the photosphere. There, at the beginning of the chromosphere, the temperature again increases until it reaches one to two million degrees at 15,000 km where the corona, the sun's outermost layer, begins.

The steady state of the sun is often disturbed by a number of transient phenomena lumped together under the term, "solar activity." The most easily observed active features are the sunspots, first discovered by Galileo in 1610. The numbers and sizes of these vary over the years in the 11.6 year sunspot cycle. Spectroscopic accessories for solar telescopes, and solar radio telescopes have revealed a number of other forms of activity. The most important of these are the solar flares and related phenomena, all of which are closely associated with the sunspots in "active centers" and share in the sunspot cycle. The active center shows extraordinary complexity. The sunspot cycle passed its minimum in mid-1964, and should reach its next peak late in 1968. During the

report period, solar activity increased steadily, and the direction of research at the Sacramento Peak Observatory has increasingly emphasized the study of the active features.

Prominences and flares originate in the photosphere. Prominences take many forms, but generally they are clouds of low density material which shoot up to heights of 50,000 to 200,000 km, and last 20 to 60 minutes. Associated with flare activity are abrupt environmental disturbances in space and in the ionosphere, some of which strongly affect Air Force operations. The most spectacular of these are the showers of high energy (about 100 MeV) protons which are capable of damaging equipment and which are biologically harmful. Another associated activity is the emission of x-rays and clouds of low energy (about 100 keV) particles which alter the height and intensity of ionization in the terrestrial atmosphere and excite the aurora. These abnormal ionospheric effects occasionally black out long distance radio communications and produce confusing radar returns. Changes in the density of the upper atmosphere also occur, altering the aerodynamic drag on low flying satellites.



By coincidence, astronomers at the Sac Peak Observatory photographed an AFCRL balloon launched from Holloman AFB as it crossed the disk of the sun.

The primary purpose of the research program of the Sacramento Peak Observatory is to identify specific forms of solar activity which produce environmental disturbances in the earth's atmosphere and nearby space and to devise reliable methods for predicting the disturbances. The most important of the disturbances are high energy proton showers. They are invariably associated with large flares in active centers, although only 30 percent of the large flares produce proton showers. Thus, if periods free of major flares can be predicted, there is then assurance that the period will be safe from protons. This is the first step toward direct predictions of the proton showers.

Observatory scientists have taken two approaches to the prediction of flares, one empirical, the other concerned with physical cause and effect relationships.

EMPIRICAL PREDICTION APPROACH: The Solar Patrol Program, carried out since 1951, falls into the empirical category. Telescopes of moderate size continually record the state of the sun photographically during all daylight hours. The films are searched daily for interesting forms of solar activity, and the data transmitted by teletype to the Air Weather Service Solar Forecasting Center, ESSA, and other interested users.

Experienced patrol observers manage to be ready and waiting at a telescope whenever a large flare appears. Through years of experience they acquire a feeling for the precursory features in an

An active center surrounding a sunspot, such as the one photographed here in the Ha line, is often a precursor to geomagnetic disturbances. The bright areas are Class II solar flares.

active center that may lead to a flare. In part, they can specify the danger signs, but there are additional subtleties which the observers cannot describe that lead to the conviction that a flare is imminent.

Since 1961 the Observatory has predicted safe periods during which no flares are expected on this highly personal "artistic" basis. In spite of its informality, the method has been moderately successful during the years of low activity in the sunspot cycle. Every proton shower without exception has come during a period designated as dangerous. However, two major flares without proton showers have come during intervals designated safe. Both of them were very unusual. They occurred in relatively quiet regions of the sun well removed from any vigorous active centers around sunspots, a circumstance that ordinarily would eliminate any chance of an accompanying proton shower.

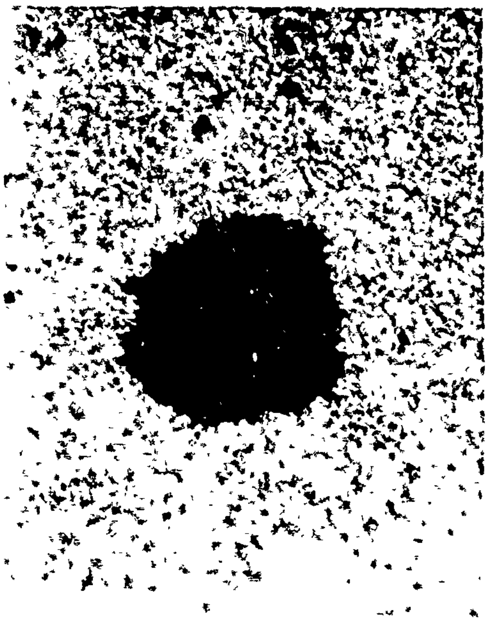
The major fault of this empirical prediction method is that many false alarms are called in an effort to take no chances. The false alarms, which consumed about 30 percent of the time, are not serious during the sunspot minimum. However, as the activity increases, false alarms become more frequent and can be expected to consume more than 80 percent of the time in the years of sunspot maximum. Such predictions would then be of little use. One objective, then, is to pin down the significant flare precursors more explicitly, and to distinguish in advance between flares that produce protons and those that do not.

Since the visual appearance of the active centers seemed to give only uncertain indications of coming flares, the Observatory has moved in two fresh directions to improve the observations. Two new kinds of instruments have been built, a video playback system, and a videometer.

Although rapid changes occur in active centers, they are usually imperceptible to a real time observer because the variations normally take place in minutes rather than seconds. Activities which escape the observer altogether become conspicuous when viewed in a lapse time movie. The video playback system records the image of an active center on video tape at intervals of 10 seconds. On demand, it plays the tape back on a video screen at 30 frames per second, showing the history of the center over the past several hours leading up to its current configuration. The system has not been in operation long enough to enable the observers to sort out the significant solar transients, but it promises to add a most important dimension to forecasting.

The videometer also receives the solar

image on a video tube. It processes the output signal to give a continuous strip chart recording of the area, integrated intensity, and peak intensity of a flare (or any other bright area on the sun) as a function of real time. In the past, areas have been laboriously measured and peak intensity estimated from the photographic patrol records at the end of the day. The videometer gives instant quantitative data that have never before been available. The hope is that the peculiarities evident in the time variations of different flares will permit discrimination between those that produce protons and those that do not. This would provide a useful positive three-hour warning.



The striations seen leading into the center of this simple sunspot are the result of magnetic field lines. The grains of the granular surface in which the sunspot is embedded average more than 500 km across.

PHYSICAL PREDICTION APPROACH: Physical proton prediction methods should eventually be far more reliable than the empirical statistical methods, the only ones so far available. They depend on a knowledge of cause and effect in active centers. A flare has all the earmarks of a sudden release of tension that has gradually mounted to the point of instability. It is like the breaking of an over-wound clock spring. When the physics of this process is really understood, it will be possible to designate the observable features that are symptoms of the windup.

For lack of any other adequate source of energy, the powerful magnetic fields of the active center are generally regarded as the basic source of all flare activity, either directly or indirectly. There are a number of theories which account for the conversion of magnetic to flare energy by the annihilation of magnetic fields. Such a theory, developed at the Observatory to account for actually observed peculiarities of the flares, leads to the expectation of an observable configuration and changes of the magnetic fields in an active center. If the theory is correct, the size, shape, and time of occurrence of any large flare could be predicted from the magnetic observations.

The analysis of the observations, which show only the line of sight field component at one level in the solar atmosphere, is a formidable computational problem, though reasonably straightforward in principle. It involves a complete reconstruction of the field above the level of observation. The machine program for this computation has been written and successfully tested. It is adequate for research purposes, but must be drastically shortened for real time use.

Another approach to physical prediction has yielded an apparently reliable

short term prediction method for one peculiar class of flares. A few long string-like dark filaments are normally present on the solar disk, usually well away from active centers. They are simply large quiet prominences which lie in troughs in an otherwise horizontal magnetic field of a few tens of gauss. Occasionally the intrusion of the fringes of an active center field will distort the prominence field and abruptly cause the trough to hump up into a mountain. The prominence suddenly rises. The appearance at the limb is shown in the accompanying figure. Observatory astronomers have shown that the prominence material flows down the sides of the magnetic mountain into the underlying solar atmosphere. The kinetic energy is converted on impact into flare-like brightenings, which characteristically take on the form of two bright ribbons, one on each side of the original filament.

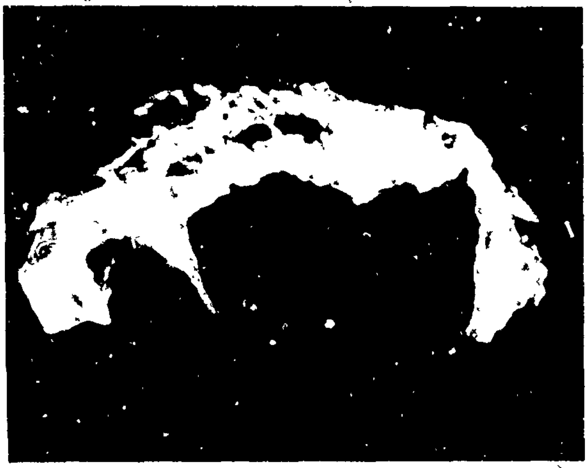
The present indication is that none of these brightenings away from active centers produce proton showers. However, there have been many observed instances where the same mechanism appears to operate in active centers, although the cause and effect relation is more difficult to trace in these complex regions. More critical observations are being made to decide definitely whether the same process occurs in active centers. If it does, Sac Peak astronomers will have a messy situation in which both direct and indirect magnetic activities produce flares. This might, however, be the distinction between large flares that do and do not produce proton showers. If so, the ability to make this distinction would reduce the time wasted in false alarms by a factor of two or three.

CHROMOSPHERIC STRUCTURE: The chromosphere is the most inhomogeneous layer of the solar atmosphere. At the solar limb the chromosphere appears in Ha as a fur of bright spicules, little hairy spikes of gas, 5,000 to 10,000 km high, and less than 1,500 km thick, projecting upward from an irregularly defined continuous layer. A lively controversy is presently in progress on the role of the spicules in the chromosphere.

Does the chromosphere consist wholly of a forest of spicules, too numerous to be individually resolved at the lower levels but with a few exceptionally high individuals that are seen separately higher up? If so, the spicules should be surrounded by coronal gas at extremely low density and high temperature (about 1,000,000 degrees K). Or are the spicules immersed in a continuous chromospheric atmosphere of relatively high density and low temperatures (about 10,000 degrees K)?

Proponents of the spicule forest theory point out that it neatly accounts for the low intensity of high frequency radio noise from the chromosphere, and the double reversal of the H and K lines of Ca II on the solar disk. They also found a "second limb" on Ha filtergrams and spectroheliograms, a ghostly image of a sharply defined outer boundary somewhere near the level of the solar limb seen in white light. They have contended that the second limb is the outer boundary of the continuous solar atmosphere, visible through the interstices between spicules, even though the spicules are too closely packed to be seen separately. The Sac Peak astronomers proved that the "second limb" is a purely instrumental effect due to scattered light.

Whatever the interspicular medium may be, spicules are seen through it, and its effect should be seen in the spectra of spicules. Sacramento Peak astronomers have looked for spectroscopic characteristics that would decide the question. The strongest, broadest, and brightest lines in the spectrum of a



Large prominences such as this may explode outward from the solar surface to distances of 100,000 km in less than an hour.

spicule are Ha of hydrogen, and H and K of ionized calcium. These lines are "self reversed"—that is, a narrow dark line appears in the center of the strong bright line. Self reversals could be produced in the spicules themselves, if their density is sufficiently high, or could be due to absorption of light from the spicule as it passes through a cooler interspicular medium. Observatory astronomers showed that the latter is the case.

The spicules are a decidedly dynamic phenomenon, with mass velocities in the 20 to 40 km per second range. Often a large component of velocity lies along the line of sight, producing a substantial Doppler shift of the spicular line spectrum. The Sac Peak spectra shows these wavelength shifts very clearly. They also show that the dark self reversed lines in Ha, H, and K do not share the Doppler shifts of the bright spicular lines. The material producing the self reversal, therefore, is not moving with the spicule material. AFCRL astronomers concluded that the dark line is due to a stationary interspicular medium at the temperature and density favorable for the absorption of Ha, H and K. At heights above 6000 km the self reversal fades out. Hence, the lower spicules are immersed in a continuous chromospheric atmosphere, which interfaces rather abruptly with the hot tenuous corona at about 6000 km. The highest spicules extend up into the corona.

The study of spicule spectra yielded other significant facts. The spicular structures shown in the hydrogen and helium lines are very well correlated, but are much less well correlated with those shown in the H and K lines of ionized calcium. This means that the excitation conditions vary over a wide range from spicule to spicule. The low level rare earth lines show no spicule structure whatever and are probably emitted exclusively by the interspicular

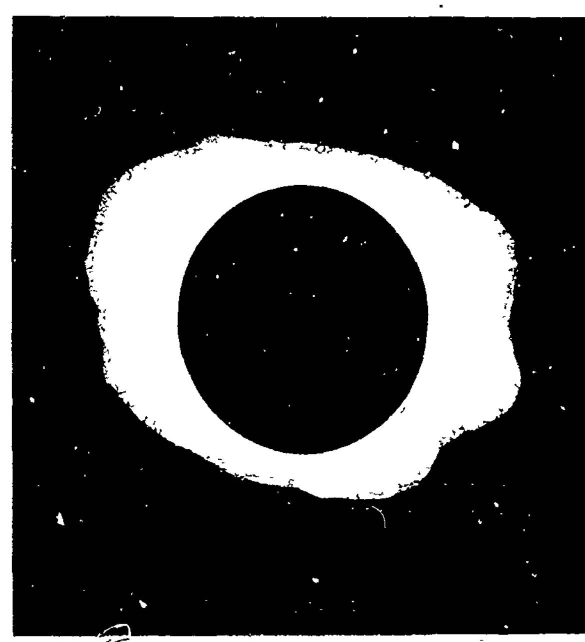
When the disk of the sun is artificially eclipsed, spicules (the furry pattern of gases) are clearly seen projecting from the chromosphere. The length of this frame covers about 160,000 km.

medium. Finally, many of the spicules show Doppler line distortions peculiar to axial rotation. These spicules appear to ascend with material spiralling around the long axis of the spicule.

VERTICAL STRUCTURE OF THE SOLAR ATMOSPHERE: Over the past 15 years the many theoretical models of the solar atmosphere (one for each theoretician) have converged to an agreement marred only by differences in minor detail. One established feature is a temperature minimum of about 4500 degrees K a little below the top of the photosphere. The solar atmosphere is most transparent in visible light, and becomes increasingly opaque toward the infrared and the ultraviolet. Thus the visible light of the solar disk comes from below the temperature minimum at the center of the solar disk (with vertical incidence) and from just about its level at the limb (with less penetrating grazing incidence). Because the brightness falls off with the temperature of the emitting gas, the limb appears darker than the center of the disk in visible light. In the far infrared, however, according to the accepted model, just the reverse should be observed. In the infrared, one should expect a limb brightening.

Since this is a critical test of the accepted model of the solar atmosphere, AFCRL and Smithsonian Astrophysical Observatory astronomers measured the brightness profile of the solar limb at 24 microns with the 60-inch reflector of the University of Arizona. The expected limb brightening was not observed. Nor was it observed in a far more critical test during the eclipse of November 12, 1966 in Peru. The impact of these observations has not yet been fully realized, but it will require some sweeping modifications of the models of the solar atmosphere. The initial suspicion is that the present models have failed because they neglect the complicated inhomogeneities that are so apparent in the observations of granulation and the spectra of the photosphere.

ECLIPSE EXPEDITIONS: Solar eclipses provide two unique observing situations. First, the eclipsing of the bright solar disk reduces the background brightness by a factor of nearly 10^6. Details of the corona and chromosphere, which are usually many times fainter than the normal blue sky, stand out during eclipse against a relatively dark background and can be studied without the overwhelming contamination of non-coronal scattered light. Secondly, the motion of the moon across the solar limb permits the study of height variations in the limb phenomena with a resolution limited only by the speed of recording. Un-



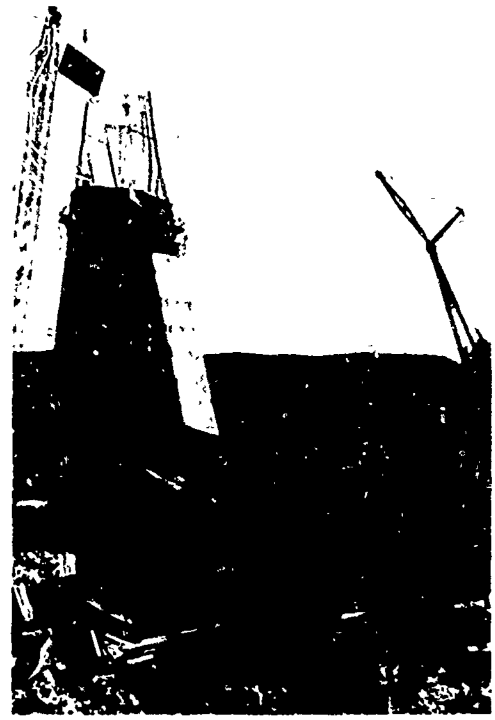
The eclipse expedition of May 30, 1965 resulted in the discovery of eight new coronal lines. AFCRL has formulated several theories on the relationship between the corona and solar winds.

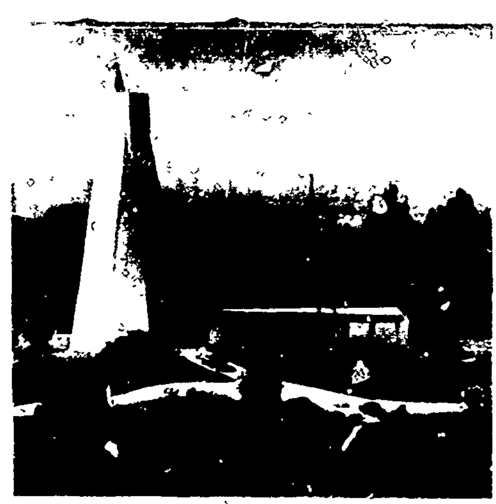
der the best non-eclipse seeing conditions, resolution of 600 km in height is extremely good. At an eclipse, height resolution of 100 km is usual.

Sacramento Peak Observatory personnel observed the eclipses of May 30, 1965 and November 12, 1966 from the ground and from aircraft. In 1965, a joint ground expedition from the Observatory and the University of Hawaii obtained spectrograms of the corona that showed the lowest threshold of line brightness yet achieved. An identical telescope-spectrograph of data was obtained from an airplane at 37,000 feet with a notable decrease in contamination by atmospheric absorption lines. The observations were a great success technically and resulted in the discovery of eight new coronal lines (out of a total of 38). A second effort at the 1965 eclipse was the observation from aircraft of polarization of the 5303 line of FeXIV. Russian astronomers had reported a theoretically impossible degree of polarization in this line and in the 6374 line of FeX. The AFCRL observation showed the predicted polarization. Its orientation unmistakably showed the presence of coronal magnetic fields.

During the November 1966 eclipse, the Observatory successfully repeated the aircraft borne coronal spectrum observation.

TOWER TELESCOPE: The study of small details in the solar atmosphere has been the key to most of the advances in solar research of the past ten years. The basic obstacle to such studies is achieving high spatial resolution. The theoretical resolution of a solar telescope is rarely realized because of slight temperature inhomogeneities in the air inside the telescope and between the telescope and the upper atmosphere. They refract the light unevenly and produce image shimmer.





Construction of the new solar vacuum telescope began in 1965 and is scheduled for operation in the fall of 1968. The upper photo shows the status of construction as of October 1967. A model of the telescope is seen below. Of the total 335 foot length, 220 feet are below ground.

The construction of an evacuated tower telescope, uncompromisingly designed by Observatory scientists to achieve the highest resolution and freedom from scattered light, began in May 1965. The instrument should be completed by September 1968. Total telescope length is 335 feet.

The telescope itself is a fixed vertical reflector of 30 inches aperture and 180 feet focal length. Two tracking mirrors at the top of a solid concrete tower 135 feet high feed the light to the objective mirror at the bottom of a 220-foot well which forms the solar image at ground level. The whole system is enclosed in an evacuated steel tube with an easily cleaned quartz window in front of the tracking mirrors. Thus, all the critical reflecting surfaces are protected from dust, and the internal optical path is free from convective inhomogeneities. The light enters the telescope high above the worst atmospheric convection which normally dies out at a height of 100 feet or so. The remaining atmospheric effects above the telescope will be troublesome at times, but past experience at Sac Peak clearly shows that there will be many long intervals of excellent "seeing". The Observatory expects a factor of two in resolution (which increases the information content of an observation by four).

RADIO ASTRONOMY

The Laboratory's radio astronomy program is centered at the Sagamore Hill Radio Observatory in Hamilton, Massachusetts. At this site (54 degrees geomagnetic and 43 degrees geographic North), is located an 84-foot equatorially mounted radio telescope, a 28-foot equatorially mounted solar telescope, a 150-foot alt-azimuth radio telescope, an 8-foot equatorially mounted telescope, three log periodic antennas, and diverse yagis and vertical whip antennas. Frequencies range from 19 MHz to 8800 MHz.

Studies involve the radio energy from the sun, the moon, radio stars, cosmic background, satellites, interstellar gases, and the planets. Of primary interest is the effect of the atmosphere on this energy. The radio astronomy research program at AFCRL relates to Air Force systems for detection, communication, navigation and guidance.

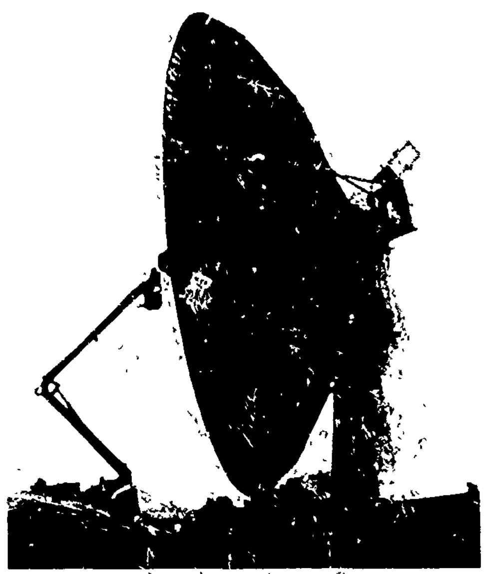
A major effort during the period was devoted to the calibration of the Sagamore Hill solar radio telescopes. The radio physicists at the Observatory are confident that all fluxes recorded from

Framed by the 84-foot radio telescope at Hamilton, Mass., is a 150-foot radio telescope. A log periodic antenna is shown in the middle region.

the solar telescopes are realistic to within 10 percent of the true flux, and for 606 MHz operations, to within 3 percent. Calibrations were made using Cassiopeia A and the moon. A member of AFCRL's radio astronomy group has been named to serve on the nine-man international working group on absolute calibration.

During the period, increasing use was made of the signals from satellites. Synchronous satellites have proved to be particularly useful because their stationary positions relative to the ground receiver permits observers to obtain an unambiguous record of diurnal variation in signals.

The increased use of satellite signals to study the atmosphere between the earth and deep space has resulted in the establishment of an international coordinating body, the Joint Satellite Studies Group sponsored in part by NATO. The Group coordinates the activities of observing stations all over the world. Of the 28 technical papers presented at the October 1966 meetings of the coordinating body, seven were by members of AFCRL's radio astronomy group.



Different types of feeds are used with AFCRL's 84-foot radio telescope. Mobile equipment is available for facilitating these feed changes.

SOLAR RADIO MONITORING: The reporting period witnessed a substantial expansion of research on solar radio emissions. This new solar observation program, carried out with the assistance of Air Weather Service personnel physically located at Sagamore Hill, is an integral part of the large Laboratory effort in space forecasting discussed in a later section.

Beginning in January 1966, continuous daily observations of the sun have been made at 606, 1415, 2695, 4995, and 8800 MHz. In 1967, two additional frequencies—15,400 and 200 MHz—were added. At any given frequency, the strength or flux of these emissions changes rapidly and often unpredictably. How do changes in flux at certain frequencies correlate with solar and terrestrial effects—solar proton showers, solar flares, magnetic storms, auroral displays, and radio communications blackout? Can certain characteristic changes in radio emissions be identified as precursors to these observed effects? Can they provide a basis for prediction?

These relationships are known in a general, qualitative way. But there has been an absence of continuous, long-term data permitting statements of these relationships with any degree of assurance. The seven different frequencies are monitored at the radio observatory continuously from sunup to sundown seven days a week. Consistent records are maintained of absolute flux values. No other radio observatory in the U. S. is making such continuous, long-term measurements. Daily records are distributed to a variety of Government and

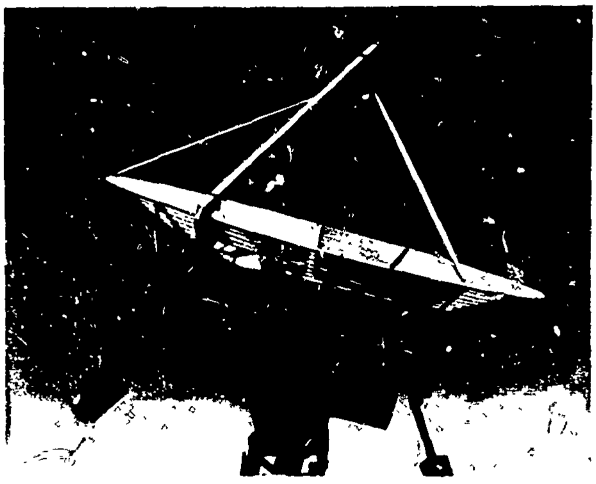
non-Government users. Solar noise bursts are reported immediately.

Two of the smaller radio telescopes at the Sagamore Hill Radio Observatory are used in these studies—one with a 28-foot dish, the other with a dish of eight feet The eight-foot telescope provides flux values at 2700 and 8800 MHz. A multi-frequency feed (which includes provision for 5000 MHz output) is used on the equatorially mounted antenna. The outputs of each of the radiometers are recorded on dual channel paper records. One channel of limited dynamic range is used for the small daily variations of the flux, the slowly varying components of the sun's radiation. The second channel is used for recording the burst activity which may rise to many times the solar background.

The equatorially mounted 28-foot antenna has two radiometers at its output, one at 606 MHz and the second at 1415 MHz. It is also set up to record the flux of the slowly varying component and the bursts from solar flares. The output of this unit is fed to digital equipment as well as to paper chart recorders.

The flux of radio emissions peaks at different frequencies depending on the source region. Sunspots emit energy in the spectral range of 1415 to 10,000 MHz. At 606 MHz, the radiation is from the outer layers of the solar atmosphere, the corona. At 8800 MHz, the radiation is from the chromosphere, closer to the sun's visible surface.

In 1966, more than 1200 distinct solar events were recorded in centimeter wavelengths alone. It is expected that this number will grow to about 3500 in 1968 for the same coverage.



The 28-foot telescope above is devoted exclusively to AFCRL's solar flare patrol program and is pointed constantly at the sun during daylight hours. Receiving and recording equipment associated with the telescope is shown below.

SOLAR ECLIPSES: Radio measurements were made of two 1966 solar eclipses to study coronal condensations in the solar atmosphere. These condensations are an important part of the active regions from which flares, particles, and radio emissions emanate. A knowledge of these condensations is essential to the understanding of flare mechanisms. Eclipses make possible the study of small localized regions as the moon crosses the solar disk and shields adjacent regions.

The first 1966 eclipse occurred in Greece on May 20 and was an annular eclipse of magnitude 0.99. This study was conducted jointly with the National Observatory of Athens. Simultaneous measurements were made at 8800, 4995, 2695, and 1415 MHz with a single portable 8-foot diameter radio telescope. Three prominent condensations and one weaker one were present on the sun during the time of the eclipse. The data obtained clearly shows the covering and uncovering of these regions. Independent rocket measurements showed these regions of both X-rays and EUV.

The same equipment used in Greece was later sent to Ancon, Peru, where, in cooperation with the Instituto Geophysico del Peru, measurements were made of the November 12 total eclipse, magnitude, 1.018. Again, good data were obtained of some unusual condensations in the solar atmosphere. A very large and complex region was present near the center of the sun which contributed a sizable portion of the solar flux and created an unusually broad minimum in the total eclipse curves.

This equipment in 1966 was twice shipped overseas for solar eclipses, first to Greece on May 20 and later to Ancon, Peru, for the November 12th eclipse.

From these eclipse measurements, it will be possible to obtain the following information on condensations: 1) spectral emission characteristics of each of the regions; 2) their size and height in the solar atmosphere as a function of frequency; 3) the electron temperatures and densities of the condensations, and 4) an estimate of the magnetic field strengths in the vicinity of the localized regions.

The equipment developed for the eclipse was subsequently modified to provide an auxiliary solar radio patrol in Manila, P.I., similar to that at Sagamore Hill, but for times when the sun is not visible at the AFCRL site. Operations will be under the uniform calibration control of the AFCRL radio astronomy group.

OBSERVATIONS AT ARECIBO: Observations were made at four frequencies in the 20 to 40 MHz range using the 1000-foot radio telescope of the Arecibo Ionospheric Observatory in October-November 1964, April 1965, and March 1966. Flux densities and spectra of nine discrete radio sources were measured.

These observations led to the development of a model to explain the scintillation (intensity variations) of optical and radio signals passing through the atmosphere. The models explain why some sources scintillate while others do not. With this model, scintillation is shown to be primarily a function of the angular diameter (apparent size) of the source.

The study shows that the smaller the angular diameter of the source, the greater the scintillation. Thus, stars with small angular diameters twinkle; planets with larger angular diameters do not. The study also indicates that the rate of scintillation does not in general

vary with frequency. Eight signal sources above the atmosphere were studied. Angular diameters ranged from less than one second of arc to 29 minutes of arc. Observations were made with radiometers operating in the 22.30 to 38.75 MHz range.

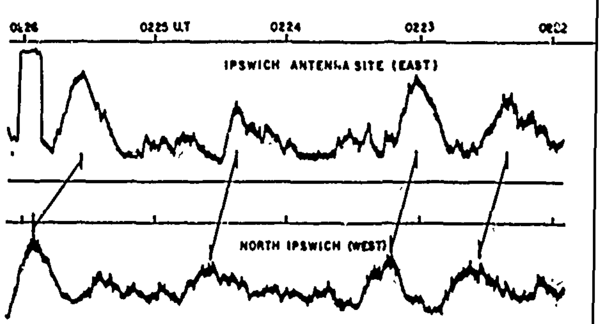
There would, of course, be no scintillation regardless of the angular diameter of the source if the signal did not pass through the uneven and irregular layers of the ionosphere. It is possible, therefore, to learn something of the dimensions of ionospheric irregularities by analyzing scintillations—and in fact many researchers have done just that. Usually this has involved a number of receivers spaced over a large area on the ground. Because scintillation itself is nothing more than variations in the amplitude of the received signal, it is possible to compare the signals received at these spaced receivers and to derive information on ionospheric irregularities. The AFCRL study shows that it is possible to derive information on the dimensions of ionospheric irregularities using a single receiver if the angular diameter of the source is known.

The March 1966 Arecibo observations were largely concerned with the Galactic Spur, an extended region of unusual radio brightness which juts out from the galactic plane. Contour maps of radio brightness at four operating frequencies in the ridge structure of the Spur were plotted.

SATELLITE COMMUNICATIONS STUDIES: Air Force communications and navigation systems being proposed envision transmissions and reception in the 50 to 250 MHz range using synchronous satellites. Most attention has been given to a 136 MHz system for voice communications and air traffic control over the Atlantic Ocean. Scintillations or fluctuations in amplitude of the signal is the basic atmospheric problem encountered by this system. Observations of signal variations of interest to communications engineers have been made by AFCRL and contractor radio astronomers at Thule and Narssarssuaq, Greenland; Greenbank, West Virginia; Arecibo, Puerto Rico; and Huancayo, Peru, as well as at the Sagamore Hill Radio Observatory.

Much effort has been placed on the reduction of satellite and radio star data to forms directly useful to communication engineers. Comparisons of Transit 4A data with 136 MHz Early Bird data have established a significant daytime peak of ionospheric irregularities which occurs only during the spring months. The relation of this feature to sporadic E is under study.

The relationship of ionospheric irregularities to solar activity is of particular importance in the operation of aircraft communication and navigational surveillance systems which propose to use VHF communications via mid-Atlantic satellites. Design engineers would like to be able to predict the onset of extensive



Here are pen chart tracings of scintillations of the Early Bird satellite taken at the same time at two AFCRL sites about 4 km apart. The scintillation peaks, separated by about 30 seconds, result from movement of ionospheric irregularities.

scintillation. One example of a predictive parameter was the discovery, following an AFCRL analysis, that deep fading increases sharply at high latitudes on the sunlit side of the earth during magnetically disturbed periods.

A statistical comparison of scintillation for the satellite Transit 4A and for Cassiopeia A was completed. By carefully limiting the samples to data taken under equivalent conditions, the ratio of scintillation indices may be derived. This study permits satellite observations to be normalized for direct augmentation of radio star studies. It also confirms that the mean effective height of the irregularities is slightly above the F region peak and that the effect of layer thickness is not sufficient for HF and VHF scintillations at mid latitudes.

ELECTRON CONTENT MEASUREMENTS: During the summer of 1965, continuous total electron content measurements of the ionosphere were made using VHF radio signals from the Early Bird satellite. Measurements of total electron content were also made in December 1966 using radio signals from the satellite ATS-B as it drifted in a nearly geostationary orbit.

The observed nighttime decrease of the summer 1965 electron count data has been compared to a simple theoretical model of nighttime ionospheric behavior. The theoretically derived nighttime decrease assumed an exponential height dependence of effective attachment coefficient and an alpha Chapman ionospheric height profile. Agreement between actual count values and the simple theoretical model was good. This indicates that during the summer of 1965 (a low sunspot number year) little if any nighttime electron flux entered the mid-latitude ionosphere. The winter 1966 nighttime electron content did not decay, but remained constant—even increased in some nights—indicating significant nighttime flux in the winter.

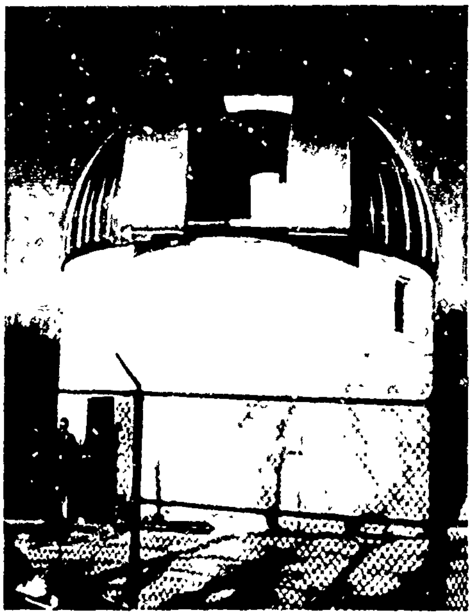
Total electron content changes observed at two sites, Sagamore Hill, Hamilton, Massachusetts, and Greenbank, West Virginia, showed on several occasions simultaneous increases in electron count. These sites, whose sub-ionospheric coordinates are separated by approximately 32 minutes of time were subjected to several large simultaneous electron flux increases. No increases in solar flux were noted at the times of these observations. The incoming electron flux has been interpreted as either a large scale traveling disturbance or an input into the ionosphere from the exosphere. These increases were typically about 10 percent of the total electron count at the time.

Further studies of total electron count will be made after the launch of the ORBIS HIGH beacon, scheduled to be placed in a near synchronous orbit in late 1967. In addition to a transmitter operating on 10.004, 15.018, 30.012, and 30.112 MHz, there will be a tracking beacon at 136.62 MHz. All transmissions will be two watts into a dipole antenna. The satellite is planned to drift eastward at the rate of one degree per day. In addition to electron count studies, it will also be used for studies of diurnal changes in scintillation and ionospheric absorption.

LUNAR AND PLANETARY RESEARCH

AFCRL's lunar and planetary investigations are concerned with the chemical and mineralogical composition of the moon and planets and their atmospheres. The research also is concerned with their general environment, including topography, temperature, radioactivity, density, and so on.

Direct measurements of lunar and planetary environments are made using



AFCRL's Lunar Observatory is located in Concord, Mass., with the primary instrument being a 24-inch telescope.

ground-based telescopes, balloons and rockets. During the report period, AFCRL placed in operation at Concord, Massachusetts, a new lunar observatory with a 24-inch telescope. Two balloons carrying 24-inch telescopes were launched during the period; a rocket carrying a five-inch telescope was also launched.

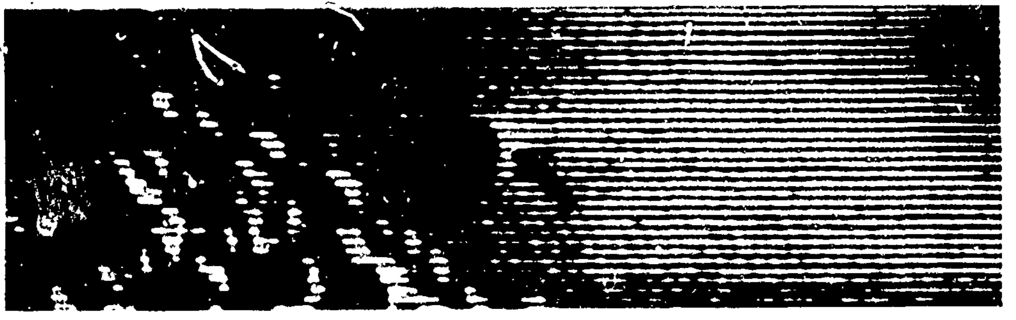
With these facilities, infrared spectroscopic measurements were made to determine chemical and mineralogical composition of the moon. Theoretical studies undertaken during the reporting period include an examination of the origins of various lunar surface features, the relation of impact cratering and volcanism, the origin of the light and dark areas on Mars, and the nature of the Martian soil.

It is interesting to note that the results of the lunar soil tests by Surveyor III in 1967, in which the lunar soil was described as having the consistency of wet sand, had been predicted by Laboratory scientists in a paper delivered at the AAAS meeting in 1965 in Berkeley, California. This paper, in which experiments at AFCRL with pulverized material (silicates) in a 10^{-11} torr vacuum were reported, concluded that the particles would adhere with the consistency of wet snow and that this effect would aid in supporting the weight of the astronauts and their spacecraft and would provide good traction for lunar exploration vehicles.

GROUND-BASED OBSERVATIONS: Telescopic experiments were carried out on the AFCRL 24-inch telescope in Concord, Massachusetts, and on the Perkins 72-inch telescope in Flagstaff, Arizona.

Infrared spectroscopic experiments with these telescopes have detected very small differences in the emission spectra from different locations on the lunar surface, a discovery noted in the previous report. Differences in emission, resulting from changes in molecular vibration spectra, have been interpreted as resulting from changes in mineralogical composition from place to place on the moon.

Thermal experiments have also been carried out on these telescopes. These experiments involve a unique infrared imaging system, which has produced infrared images with the highest spatial resolution yet obtained. The lunar crater Tycho was of special interest, because previous measurements had shown it to be hotter than the surrounding lunar surface. Some had speculated that the hot spot was of possible volcanic origin. Infrared images of the thermal anomaly associated with the crater were obtained during the lunar night 97 hours after Tycho had ceased to be illuminated by the sun. In agreement with previous studies, these measurements showed that the crater is warmer than its surroundings during the lunar night. The higher



Using an infrared imaging system, temperature measurements of the lunar surface can be made. The arrow points to a spot on the moon originally thought to be of volcanic origin but which AFCRL proved to be the result of absorbed solar energy.

spatial resolution of this experiment showed also that the steeper crater walls facing the sun prior to local sunset were warmer than walls facing away from the sun. This indicates that the Tycho thermal anomaly is produced by solar, rather than internal heat.

BALLOON AND ROCKET OBSERVATIONS: The Laboratory launched two balloons during the period, each carrying a 24-inch telescope to altitudes above 99 percent of the infrared-absorbing constituents of the earth's atmosphere. The AFCRL balloon-borne telescope system was an unmanned automatic system designed for a float altitude of 100,000 feet. This system made its first fully successful flight in March 1966, during which it obtained the first mid-infrared spectrum of the moon from balloon altitudes. This spectrum showed the lunar emission to be very similar to that of a black body, but suffered from low sensitivity. A second successful flight was made with more sensitive instrumentation on March 17, 1967. The data obtained on this flight show a clearly identifiable emission band at 7 microns.

To obtain infrared spectra completely unattenuated by the atmosphere, instruments must be carried aloft in rockets or satellites. An infrared spectrometer was flown aboard an Aerobee rocket on November 30, 1966. A lunar pointer permitted a 5-inch telescope to be pointed at the moon during flight. The first mid-infrared spectrum of the moon from rocket altitudes was obtained. Wandering of the pointer produced variations in signal level, however. This required exhaustive computer treatment of the data in order to remove this effect.

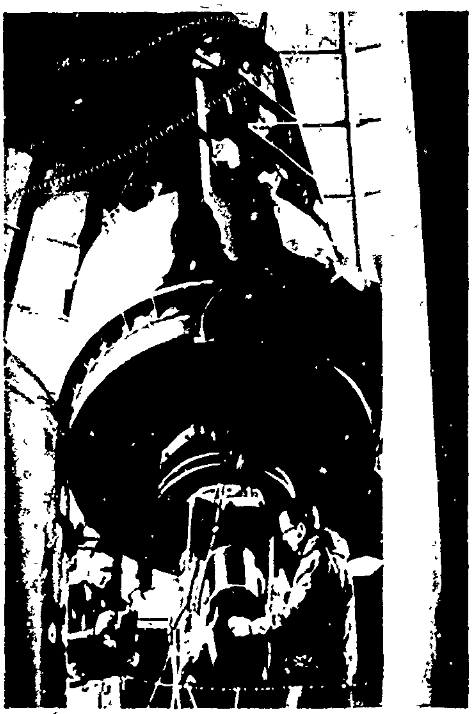
EMISSION SPECTRA OF MATERIALS: The lunar surface over a period of millions of years has been subjected to considerable space-weathering from solar light, micrometeorites, and bombardment by the solar wind. The effects of the solar wind, which consist mostly of low energy particles, are especially pronounced to the observer on earth measuring such properties as lunar reflectivity, albedo, color and polarization of the reflected lunar light. To obtain laboratory standards against which to compare observational data, rocks and minerals were subjected to radiation in the laboratory and reflection and emission spectra determined before and after radiation damage.

In one study, conducted jointly by AFCRL and Brookhaven National Laboratory scientists, the effects of bom-

bardment by a relatively small flux of high energy protons were measured. The investigators started with the assumption that the major constituents of the lunar crust are silicates and other oxygen-rich substances. When a silicate material is bombarded with high energy protons, numerous chemical rearrangements of the bonded oxygen atoms may occur. Atomic oxygen may be liberated. These free oxygen atoms may then react with incoming protons to form the hydroxyl radical, OH. The hydroxyl radical can diffuse to the surface and escape, or it can react chemically with the silicate. If the oxygen atom is partially bound to the silicate material when reaction with the proton occurs, the resultant OH is then permanently bound to the silicate lattice.

In the experiments, a Van de Graaff generator was used to bombard glass with high energy protons in the 0.15 to 1 MeV range. It was found that as much as 100 percent of the incident protons were converted to OH.

Although the study dealt only with lunar surface materials, it is clear that cosmic dust, comets, asteroids, the moons of other plants, and the total surface of the planet Mercury are all subject to the proton to OH conversion. This reaction must be considered as one of the large scale chemical reactions in the solar system.



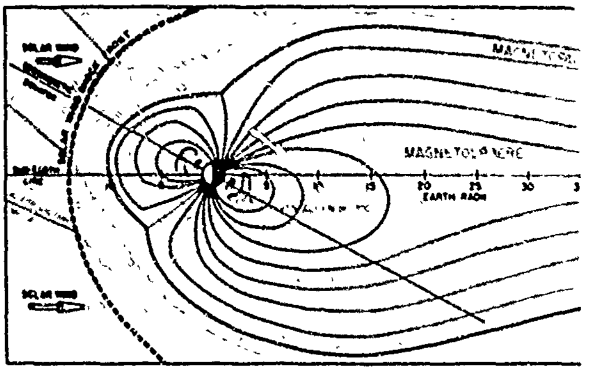
The Perkins 72-inch telescope in Flagstaff, Arizona, has been used frequently by AFCRL scientists for lunar observations.

ASTROPHYSICS

Astrophysics is the application of physics to problems of astronomy. It is concerned with interpreting observations and understanding the energy mechanisms and force fields of the stars and interstellar and interplanetary matter in terms of physical law.

Well over 99 percent of the universe is composed of ionized gases. Astrophysics research must therefore consist, basically, of the study of plasma and plasma related phenomena—hydromagnetics, excited states of ionized gases, and the complicated cooperative interactions which characterize the observable universe.

The AFCRL astrophysics research program is mostly concerned with the sun, the earth's magnetosphere, and the solar wind of protons and electrons that interconnects the earth and the sun. The dynamically varying activity within this limited system is reflected ultimately in the performance of Air Force communications and detection operations. Only rarely is it possible to consider ionized gases in space apart from the magnetic fields with which they are associated. The charged particles in space influence,



This schematic of the magnetosphere could not have been drawn in the pre-satellite era. AFCRL has instrumented many satellites which have helped define the dimensions of the magnetosphere.

and are strongly influenced by, these fields.

In addition to the plasma research conducted by the Space Physics Laboratory, strong plasma research efforts are also found in AFCRL's Microwave Physics Laboratory (Chapter VIII) and the Upper Atmosphere Physics Laboratory (Chapter IV).

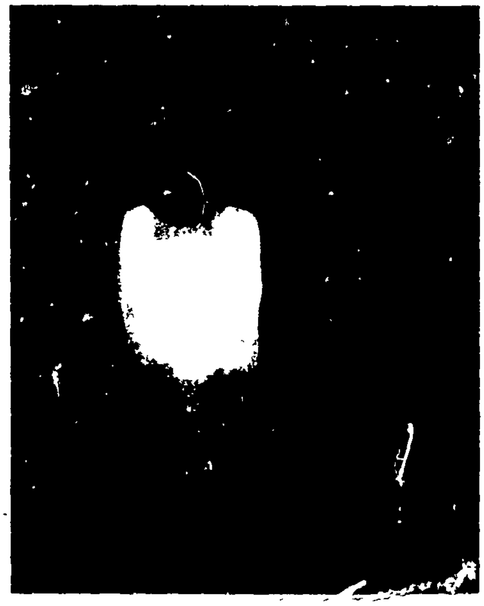
MAGNETO PLASMA INTERACTIONS: The most intriguing—and difficult—of the problems in astrophysics is the behavior of charged particles in the presence of magnetic fields. Of these problems, the behavior of the charged particles that comprise the solar wind when they encounter the earth's magnetic field provides a particular challenge to the astrophysicist.

The concept of the magnetosphere, as it is known today, didn't exist before 1957. Its structure has only been recently defined through the data telemetered to earth by scores of satellites. AFCRL has instrumented many of these satellites—most notably the OV5-1 launched on April 28, 1967 designed to monitor variations in solar radiations. The highly elliptical orbit with a 111,000 km apogee and an 8500 km perigee carries the satellite alternately into and out of the magnetosphere. Other productive satellites are NASA's Pioneer VI and VII. Pioneer VII, launched in 1966, orbits the earth at distances of more than five million km.

Interpretation of satellite observational data can be facilitated by laboratory experiments in which magnetic fields and plasmas can be controlled and parameters varied. Even so, magnetoplasma interactions are difficult to generalize; extrapolations from data points are seldom valid. What happens to the magnetic field when either the flux or the energy of charged particles, or both, are varied can seldom be predicted—nor are predictions easy when the flux and energy remain constant and the magnetic field strength is varied.

The crux of the problem is plasma instability. This applies both to high density plasma experiments in which thermonuclear reactions are sought and to the weak plasmas interacting with the earth's magnetosphere. A plasma in a magnetic field is almost always unstable when the plasma energy density is appreciable compared to the magnetic field energy density. If stable configurations could be found, more meaningful astrophysics laboratory experiments could be performed and a number of practical plasma devices could be constructed.

Since 1961, AFCRL has steadily improved the performance of a device called the Romac (Rotated Magnetic Cusp) designed to stabilize a confined plasma. This device maintains the plasma in a toroidal container with a weak permeating magnetic field surrounded by a sharp magnetic field boun-



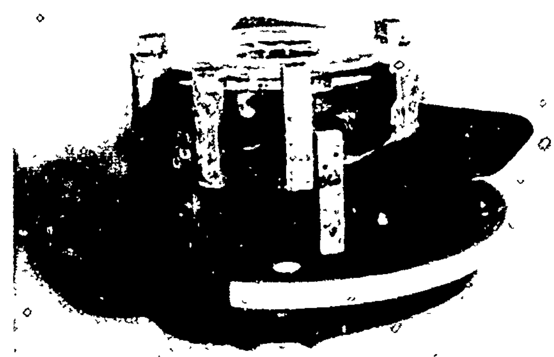
Exploding wires have been used since 1951 by AFCRL to create high density, high temperature plasmas for use in a range of plasma experiments. The evaporating wire is barely visible in the luminous plasma.

dary. Results with this device have shown unusual promise. Plasmas produced in the device are of the order of 2 x 10^{16} particles per cubic cm. This represents a pumping of background gases to densities of three times the initial pressure. Temperatures of the order of 15-20 electron volts are maintained in the central region. A type of shock heating has been successful in feeding additional energy to the plasma. The central plasma has an energy seven times the energy of the permeating magnetic field and succeeds in excluding the magnetic fields of the containing wall for about 15 microseconds.

A search has been made for evidence of instabilities and no turbulence has been found. The penetration of the magnetic field into the plasma can be explained on the basis of the classical theory and a time constant of the device. These promising results indicate that the Romac will be the first of a new class of plasma containers.

HIGH TEMPERATURE PLASMA GENERATION: Two shock tubes are used by the Laboratory to generate extremely high temperature plasmas for laboratory experiments. One of these is an arc driven tube capable of imparting velocities as high as two cm per microsecond (Mach 60). The tube itself is six inches in diameter and is 30 feet long.

A key to the development of the high velocities is a new high temperature, high pressure driver head design utilizing a prestressed alumina ceramic chamber. Driver temperatures of 28,000 degrees K have been measured (using the velocity of expansion down the shock tube). At these temperatures pressures reach 18,500 psi. This represents an

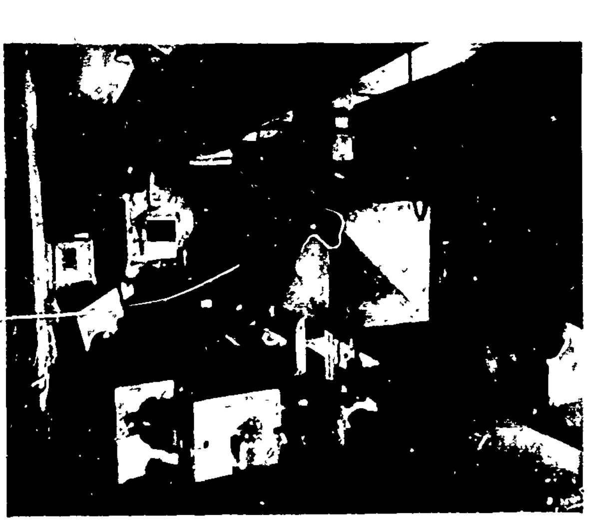


This Romac (rotated magnetic cusp) device was designed to stabilize a confined plasma. Plasma in the toroidal container is surrounded by a sharp, well-specified magnetic field boundary. The Romac may be the first of a new class of plasma containers.

efficiency of conversion of electrical energy to driver energy of approximately 50 percent. The tube is used in a variety of experiments.

The second tube is more specialized. It is 20 feet long and has a two-inch square cross section. The stainless steel tube is filled with neon. Temperatures of between 3000 and 15,000 degrees K—the general temperature range at the visible surface of the sun and most of the stars—can be achieved by creating a shock wave in the tube. The shock wave results by suddenly releasing a light gas from an associated pressure tank into the tube.

This tube is used to obtain absolute f-values. The f-value is the crucial optical constant required to find the actual number of atoms, molecules, or ions from the measured intensity of a spectral line in some "remote" gas—star, nebula, reentry plasma sheath, fireball or laboratory plasma. It is also needed in the spectroscopic measurement of electron temperature in the solar corona.



AFCRL's 20-foot long shock tube is used to measure f-values of various gases between temperatures of 3000 and 15,000 degrees K.

The specie to be measured is added in vapor form as a carefully measured trace to the low-pressure neon.

With this shock tube, absolute f-values have been measured for more than 40 strong lines of neutral chromium with five to 22 independent determinations per line and, with fewer measurements per line, for nearly a hundred weak lines of chromium and a few of iron. Chromium and iron are two of the most important gases in astrophysics and the entire iron group is important in present controversies over the origin and evolution of the universe and of the elements themselves. Simultaneous f-value determinations by photomultiplier and by photography have demonstrated that the AFCRL measures are free of photographic systematic errors. Application of these f-values to determine chromium abundance in the sun and in certain stars indicate that serious discrepancies in measurements by others may have at last been overcome.

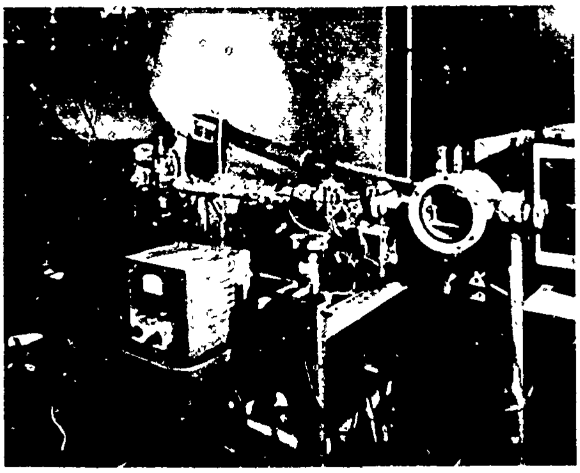
Another method used for generating extremely high temperatures for astrophysics studies is the exploding wire technique in which a large amount of electrical energy is discharged through a very thin wire. Under this high energy flux, the wire explodes, passing from a solid to a liquid to a vapor in a millionth of a second. Because of inertial factors, extremely high pressures and temperatures can be created and maintained for very short time periods. AFCRL is one of the leading laboratories conducting exploding wire research. Since 1959, three international conferences in exploding wire have been sponsored by AFCRL and the fourth is scheduled for October 1967.

SPECTRAL LINE INTERPRETATION: What is known of the composition of the stars, the sun and the solar atmosphere is known largely through spectroscopy.

But the resultant spectral lines sometimes present the spectroscopist with a decoding problem of great magnitude, particularly when the spectral lines result from ions highly excited at thermonuclear temperatures. Such temperatures cannot be attained in the Laboratory under the equilibrium conditions required for measurements. Without controlled laboratory measurements, the spectroscopist has no key for interpreting his spectral records.

With a new technique, the "foil excitation technique," it is possible, without high temperatures, to obtain quantitative laboratory spectral measurements of virtually any atom in any stage of ionization. The technique employs a Van de Graaff generator. For the AFCRL measurements, the three MeV Van de Graaff generator of AFCRL's Solid State Sciences Laboratory was used.

A high energy beam of singly or doubly charged atomic or molecular ions from the Van de Graaff generator is passed through a thin (0.1 micron) electrically conducting foil where charge exchange interactions and/or electron stripping occur between the beam ions and the free electrons of the foil. Within less than .001 nanosecond the ions emerge as atomic ions in a wide variety of degrees of ionization and states of optical excitation. All excited states begin simultaneously to undergo spontaneous decay (and hence spectral line emission) as the corresponding ions move at known constant speed straight downstream from the foil in a luminous beam. Each ion radiates its characteristic spectrum ranging from x-rays to the far infrared. Each spectral line tends to decay exponentially. Simple measurement of the distance in millimeters (corresponding to the time in nanoseconds) for any spectral line to decay in relative intensity determines the radiative lifetime of the upper state of that line.



AFCRL'S three MeV Van de Graaff generator (the target area of which is shown here) was used to measure the radiative lifetimes and a number of absolute f-values in the visual region.

The radiative lifetime is an important constant in its own right in such fields as plasma physics, and is closely related to the even more valuable absolute f-value, noted above.

SOLAR WIND-MAGNETOSPHERE INTERFACE: The protons and electrons of the solar wind do not penetrate the earth's magnetic field on the sunny side of the earth. They strike the earth's magnetic field and flow around the protective magnetic field. This is the accepted view. (High energy protons, however, can penetrate to the atmosphere in the polar regions where they do not have to cut across magnetic field lines. Protons above 15 BeV can cut across magnetic field lines at the equator.)

In experiments designed to simulate the solar wind-magnetosphere interface, AFCRL has shown that under proper conditions it may be possible for lower

energy particles to directly penetrate into the earth's radiation belts.

In the AFCRL experiments, a high velocity plasma was generated and directed into the dipole field of a pulsed coil. In accordance with the conventional picture, the plasma pressure is balanced by the pressure exerted by the magnetic field. The result is a shock front held off by the magnetic field.

But the resultant shock front is not a standing shock front. Electric and magnetic field fluctuations were found both in the shock and in the flow region between the shock and the compressed model magnetosphere. Satellite measurements of the magnetic field beyond the earth's magnetosphere have also shown such fluctuating magnetic fields. Observations of these oscillations in the Laboratory encourage the AFCRL experimenters to believe that they have correctly modeled conditions in space.

These electric and magnetic field fluctuations would not in themselves create conditions for the direct penetration of solar charged particles into the earth's magnetosphere. Another and more important phenomenon investigated was the effect on the shock front where the diameter of the plasma beam impinging on the magnetic field was varied. For these tests, apertures of varying diameters were used. As the plasma beam is narrowed, the shock becomes broadened and eventually disappears. In the absence of the shock, the narrow plasma beam can penetrate into the interior of the dipole field where the particles are trapped. The configuration assumed by the trapped particles resembles the earth's radiation belts.

Of course, there is no aperture in space through which the solar plasma passes. But it is not unreasonable to speculate that there may exist the periodic emission of intense concentrations of particles reaching the earth in a narrow beam which would have an effect comparable to that seen in AFCRL's aperture experiments.

ORIGINS OF SOLAR WINDS: The solar wind consists of a few particles per cubic cm at the earth's orbit. These particles travel at speeds of about 300 km per second. Laboratory scientists have considered theoretically the mechanism whereby these particles achieve the great energies necessary to escape the sun's huge gravity field.

Using a kinetic theory approach, this investigation took as its goal the calculation on an individual particle basis of the type of wind that would arise from a hot but quiet sun. Two very interesting features of this theory resulted in predicted values of velocity and flux that conform almost precisely with measured values. One feature is that the solar potential or electric field between the earth and the sun is shown to be relatively small, a few hundred volts.

The second is that the solar coronal exosphere (level of particle escape) is shown to act like the sheath in a discharge tube which builds up an excess positive charge and electric field. The exospheric electric potential makes the protons virtually weightless, and the sheath accelerates the thermal protons to an escape velocity of over 300 km per second. The proton density decreases with distance from the sun according to the inverse square law, and is eight per cubic cm near the earth.

A related study involves a model of the solar and extended corona based on observed electron densities in the vicinity of the sun and Explorer X proton density data in the vicinity of the earth. Temperature values were derived from 0.00025 solar radii above the solar limb outward. It is found that after five or ten solar radii, the electron density falls off inversely as the square of, and the electron temperature inversely as, the

distance from the sun. The inverse square law implies a constantly expanding model for the solar corona. The solar wind velocity over the sun-earth path is therefore constant. In order that this may be so, a postulated coronal electric field would nullify the effects of solar gravity. Values for this field are obtained assuming ambipolar diffusion.

MAGNETO-IONIC THEORIES: Many theoretical studies relating to plasma-magnetic field interactions were conducted by Laboratory scientists during the period. Two are briefly summarized below.

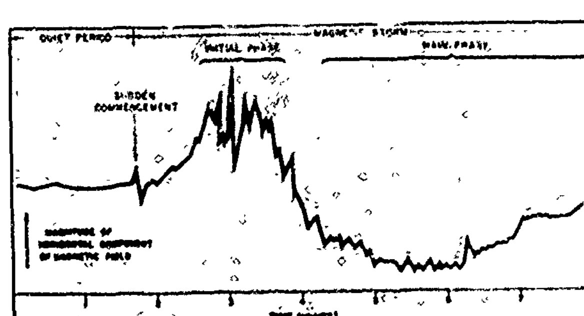
Although there are many theories for wave propagation in weakly ionized and fully ionized media, a more general theory is required when wave propagation in a partially ionized media—such as the solar chromosphere and the ionosphere—is considered. Such a theory has been derived at AFCRL for a three component, homogeneous gas (molecules, their singly charged positive ions, and electrons), in a uniform magnetic field. The theory is general enough to include electron heat flow and collision cross sections between all particles for any velocity dependence. The conductivity is derived which then leads to general expressions for wave dispersion, absorption, and joule heating. This conductivity reduces to the correct simpler expressions in the limit of weak and of full ionization.

Another general theory deals with the formation of ring current systems. The theory considers the interaction of the solar wind with the general magnetic field of the sun. It predicts that there should be a coronal ring current system with a current density equal to that in the ionosphere, but with a total current of 200 billion amp as compared with 200,000 amp for the total ionospheric dynamo current system. With increasing flux (wind), the ring current will be strengthened up to some maximum value; for still greater particle flux, the magnetic field itself will be swept away.

THE NEAR EARTH ENVIRONMENT

This section deals with phenomena taking place within the magnetically protected cavity containing the earth. The research discussed under this heading includes studies of the earth's geomagnetic field, charged particles trapped within the earth's magnetic field, and the meteorites and high energy cosmic rays that penetrate this field to the earth's atmosphere. The purpose of these investigations is to define the ambient space environment and the temporal changes it is subject to, with the ultimate goal of discovering ways of predicting these changes well in advance of occurrence.

These studies place heavy reliance on the observational data acquired by rockets and satellites, several of which were instrumented during the reporting period. Laboratory instruments were also carried aboard the X-15 aircraft, balloons and the Gemini manned vehicles.



A geomagnetic storm is marked by variations in the geomagnetic field with periods ranging from several minutes to several days.

Typical of the rocket instrumentation program was the instrumentation designed for a Javelin rocket launched on May 1, 1966 from Fort Churchill, Canada. The rocket was designed to investigate magnetic field perturbations and charged particle characteristics associated with auroral activity. A range of instruments was used—a rubidium alkali vapor magnetometer, a scale-switching fluxgate magnetometer, a search coil magnetometer, a proton detector covering a wide energy range, and a set of Geiger counters. Two similarly equipped rockets will be launched from Ft. Churchill in late 1967 and early 1968.

Laboratory scientists concerned with the development of sensitive magnetometers have more recently turned their attention from measurements of the earth's geomagnetic field to a problem of more direct military concern—namely, the detection of magnetic ground targets in Vietnam. The knowledge accrued over the years on magnetic phenomena and of magnetic field detection devices has found direct application to this military need.

GEOMAGNETIC VARIATIONS: Geomagnetic field variations are of two types, each with different origins. Slow variations, with periods or durations ranging from several minutes to days, originate chiefly in ionospheric current systems. These current systems are strongest during magnetic disturbances, and are driven by the precipitation of charged particles from the magnetosphere. The disturbances and associated currents are most pronounced in and near the auroral zones where most of the precipitation occurs.

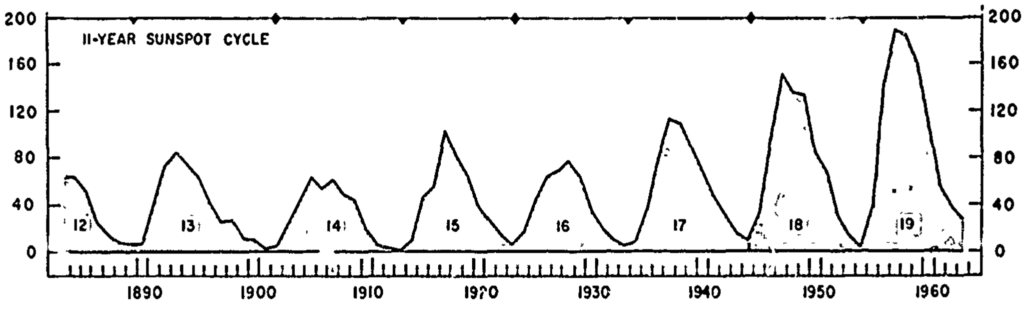
Rapid variations have two sources. Those with periods ranging from about 20 minutes down to a fraction of a second originate from hydromagnetic waves propagated downward from the magnetosphere. Most rapid variations with fluctuations at frequencies above about 1 Hz, however, originate from the world-wide distribution of thunderstorm activity.

A three-month recording program of three components of the geomagnetic fluctuations in the frequency range of 0.005 to 5 Hz was conducted at Point Barrow, Alaska; Concord, Massachusetts, and Huancayo, Peru. The program is designed to separate the fluctuations resulting from propagating hydromagnetic wave phenomena from those produced by local fluctuations of the ionospheric current system. Simultaneous occurrences of separate, discrete frequencies have been identified. The occurrence patterns and polarization as a function of time of day are studied in the light of theories of magnetospheric phenomena.

To study magnetic variations having periods greater than about a minute, the Laboratory operates, largely through contractors, a six-station network extending from polar to equatorial zones. Variable-area magnetographs are located at these sites. To reduce the data, a semi-automatic data reduction technique involving the electromechanical conversion of the analog-type photographic magnetograms is used.

TWENTY-TWO YEAR MAGNETIC CYCLE: A 22-year solar magnetic cycle is associated with the 11-year sunspot cycle. Changes in the magnetic polarity of sunspots from one 11-year period to the next were noted as long ago as 1913. The effects of this 22-year magnetic cycle on geomagnetic activity on the earth were investigated during the period.

The AFCRL statistical study considered daily geomagnetic data for an 80-year period (29,219 days) from 1884 through 1963. It was found that the earth's geomagnetic activity in one



In this plot made by AFCRL of the number of sunspots occurring during each eleven-year sunspot cycle since 1890, one sees that the number of sunspots has increased slightly during the past several eleven-year cycles.

11-year sunspot cycle period had a distinctly different pattern from the geomagnetic activity in the following sunspot cycle.

One implication of the study is that solar astronomers and environmental scientists cannot assume that IGY data collected in the late 1950's and IQSY data collected during the past 18 months will provide a valid basis for extrapolation of all environmental events during the next solar sunspot cycle. They may have to evaluate another 11-year's data before such extrapolation is possible.

The causes of the 22-year variation in geomagnetic data on the earth are related to the reversal in the magnetic polarities of sunspot pairs from one 11-year cycle to the next. The causes of this reversal and the reason why it should influence the earth's geomagnetic field are not understood. What is meant by a reversal of magnetic polarities of sunspot pairs? A sunspot can be considered as the location on the solar surface (the photosphere) where a concentration of lines of magnetic force enters or leaves the surface. Bipolar sunspot pairs usually have their joining axis in an east-west direction. During one 11-year cycle the magnetic lines leave (north polarity) the west sunspot.

All sunspot cycles recorded for the past 200 years have been identified by number. The solar cycle just recently completed, for example, was number 19. In the AFCRL study, geomagnetic disturbances that occurred during even-numbered cycles were compared with disturbances during odd number cycles. Based on daily recordings of geomagnetic activity since 1884, AFCRL found that for even-numbered sunspot cycles, geomagnetic disturbances are less severe during the first half of the cycle than during the second half. For odd-numbered cycles, the reverse is true.

MAGNETIC DETECTION OF TARGETS: The development of highly sensitive magnetometers for measuring delicate variations in the earth's magnetic field, led naturally to the application of these instruments to target detection in Southeast Asia.

Any object which contains ferromagnetic material (i.e., soft iron or steel) becomes magnetized by induction when in the earth's magnetic field. Such an object thus becomes the source of a magnetic field which in turn is detectable by means of a sensitive airborne magnetometer. The detectability of the magnetic field produced by the target is independent of such factors as visibility,

time of day, weather, vegetation, or relative velocity of the target detection system.

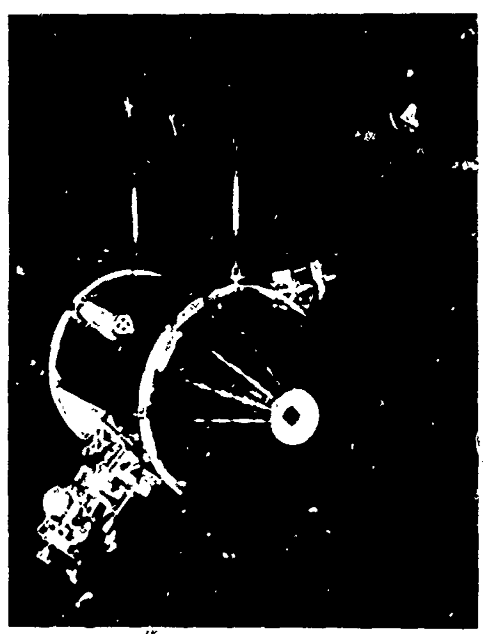
A program is underway to determine the lower limits of detectability of certain targets located in a natural, terrestrial environment and the determination of the position of these masses with respect to the airborne magnetic detector.

The magnetic fields associated with potential targets have been measured experimentally. Such information together with the characteristics of the detection equipment enables one to determine the theoretical maximum range of detection of such targets. Two types of magnetic detectors are being investigated: a component gradiometer and a total intensity magnetometer. The component gradiometer study is in the feasibility stage. Total intensity magnetometer has progressed to the point of flight tests.

IONIZING RADIATION MEASUREMENTS: Within the earth's magnetosphere, ionizing radiation of two types present a potential hazard to man and his electronic equipment when he ventures beyond the earth's protective atmosphere. These are the high flux of protons and electrons in the earth's radiation belts and cosmic rays. Both, however, are hazards only in terms of exposure over protracted periods. AFCRL has for many years investigated the flux and energies of these radiation particles. The sun is both a producer of this ionizing radiation and a modulator of particulate radiation which originates outside the solar system. Because these effects are influenced by solar activity, variations conform to the 11-year solar activity cycle. AFCRL has now collected data on variations in cosmic ray and radiation belt particle flux over most of this cycle.

(Another ionizing hazard—solar proton showers—was discussed earlier in this Chapter and is not considered here. These high energy protons are emitted from the sun during large solar flares. At lower latitudes the charged particles are deflected by the earth's magnetic field. But at the high latitude, they can follow the magnetic field lines and enter the earth's atmosphere. When they do so they can heavily ionize the atmosphere, producing as one result, polar cap absorption events which disrupt communications and detection systems in the Arctic.)

One of the first satellites recovered by aircraft in midair during descent in 1959 carried an AFCRL emulsion package of detecting cosmic rays. Satellite flights for measuring the trapped par-



The OV1-9 satellite was launched on December 11, 1966, carrying a boom-mounted, optically pumped, cesium vapor magnetometer for measuring the earth's magnetic field. The satellite was placed in a 4600 by 370 km orbit.

ticles and cosmic rays have continued since that time. The present period was marked by the development of several new types of particle detectors for measuring the flux, mass, energies and angular distributions of charged particles. The important developments were analysis of data defining the 55 MeV proton intensity between 200 and 700 km which resulted in the first direct experimental measurement of the lifetime of trapped protons at these altitudes and proof that a redistribution of trapped protons occurred as a result of the July 9, 1962 high altitude nuclear detonation (Starfish) which must be corrected for when interpreting low altitude trapped particle data. These data have been used by DASA projects to obtain agreement between the measured decay rates of electrons injected by a thermonuclear detonation and the theoretical predictions.

Three satellites and one rocket carrying instrumentation to measure ionizing radiation were launched in 1966. These were the OV3-1 satellite with a 3090 nautical mile apogee and a 19[illegible] nautical mile perigee launched on April 22, 1966; the OV1-9 satellite with a 2500 nautical mile apogee and a 200 nautical mile perigee launched on December 11, 1966; the OV1-10 satellite with a 400 nautical mile apogee and a 345 nautical mile perigee also launched from the same booster; and an Aerobee rocket launched on August 8, 1966 from Ft. Churchill.

The OV3-1 and the OV1-9 satellites carried counters capable of determining fluxes, energy spectra, and angular distributions of protons and electrons over a broad energy spectrum. These satellites—and others launched previously—have provided data on the temporal changes in the radiation environment and the processes which bring these changes about. The OV1-10 satellite carried an experiment to measure the charge spectrum of cosmic ray heavy primaries very accurately while the Aerobee rocket carried a new type of solid state detector. This new detector is unique in that it integrates the heavy nuclei observed during exposure but is completely insensitive to protons, electrons and alpha particles. Processing is far simpler than nuclear emulsions and cost of materials is sufficiently low that large areas can be exposed to detect rare events.

Concern has been expressed about possible harmful biological effects of the intensity of low energy, heavy cosmic ray particles at supersonic transport altitudes. Such low energy heavy particles have maximum ionizing effect and therefore could be a source of long-term danger to crew and passengers. This led AFCRL to design several detectors to be carried aboard a series of balloons to measure the flux of heavy cosmic ray particles. The results, thus far, show that ionization from heavy nuclei is well within biological tolerance, even for the long-term exposure of SST pilots.

COSMIC RAY TRAJECTORIES: Galactic cosmic rays approach the earth from all directions of space. When these particles encounter the earth's magnetic field, their trajectories are considerably altered depending upon the energy and charge of the particle, the direction of approach to the magnetosphere, and the magnetic field strength and configuration. Many of these trajectories are so complicated that predicting them is a mathematical problem of considerable magnitude. Using computers, AFCRL has calculated the orbits of many of these galactic cosmic rays as they traverse the geomagnetic field. During this study, the trajectories of particles with different momentum and charge, incident at more than 2000 locations around the world, have been calculated.

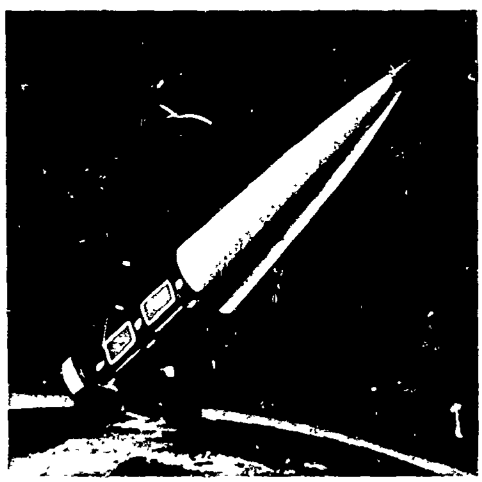
The large package on the payload bar consists of instruments for measuring and plotting the energies of cosmic rays in the upper atmosphere. Several such balloon experiments were conducted.

In considering the trajectory of a given particle it is convenient to consider momentum and charge as a single quantity called the particle's "rigidity" —the ratio of momentum per unit charge. All particles having the same rigidity, whether an individual proton or a heavy nucleus, will follow the same path through a magnetic field if they enter the field at the same place and from the same direction. The trajectories of charged particles have been used primarily in the study of vertical "cutoff rigidities," defined as the lowest rigidity a particle may possess and still arrive at a specific point on the earth's surface from the vertical direction. At the magnetic equator, where the particle must perpendicularly traverse the geomagnetic field, the effective vertical cutoff rigidity is more than 15 billion volts, while at the magnetic poles, where the particles travel essentially parallel to the field lines, it is theoretically zero.

The AFCRL study represents a significant contribution to basic knowledge of cutoff rigidities, and has resulted in a new definition of an "effective vertical cutoff rigidity." When these new values are used in the analysis of various experimental data, a greater coherence of the data is obtained than was previously possible. In addition, the accurate evaluation of vertical cutoff rigidities and cosmic ray trajectories is essential in the investigation of geophysical phenomena such as Forbush decreases, long-term solar cycle variations, diurnal variations, and in particular, solar flare radiation incident upon the earth. Also, as a result of this work, accurate tables of effective cutoff rigidities are available which serve as a uniform worldwide standard for the comparison of experimental data.

MICROMETEORITE IDENTIFICATION: Rockets, Gemini vehicles and the X-15 rocket plane during the period were all equipped with special collection plates by AFCRL to gather meteoric dust. The process of gathering meteoroid particles and returning them to the Laboratory for analysis is not altogether straightforward. Until recently two difficulties have presented themselves. One is the relatively large number of contaminating terrestrial particles usually found on the recovered plates in close association with the cosmic dust. Even when the collecting surfaces are prepared in a Federal Standard 209, Class 100 clean room, considerable contamination takes place. Contamination is reduced by shortening the time necessary to prepare collecting surfaces and sealing them in containers. Further improvements have been realized through techniques for filtering out contaminates of less than 0.5 microns in size, which is

In the above photo, the Venus fly-trap rocket nosecone used to collect micrometeorite particles is assembled in a clean room. The drawing below shows the rocket during flight with collecting surfaces extended at altitude.



the lower limit of a Class 100 clean room. Another method for coping with terrestrial contaminates is statistical. Certain collection surfaces are kept sealed during flight. These unexposed surfaces are controls used to determine the "signal-to-noise" ratio at the exposed surface.

The second difficulty that has been largely overcome is that of laboratory analysis for chemical composition. Previously, it was not possible to analyze particles smaller than three to five microns in diameter. The Laboratory, however, has recently designed and developed an instrument capable of analyzing particles down to 0.1 microns in diameter. This instrument, an electron microscope-microprobe analyzer, allows one to view the particles at magnifications up to 30,000X. An electron beam is focused on the particle and the elemental analysis is obtained by observing the particle's x-ray emissions. All elements down to, and including, Atomic Number 12(Mg) can be detected with this system.

SPACE FORECASTING

Space forecasting is self-descriptive. It is concerned with the prediction of changes and disruptive events in space and the near earth environment. These changes and events cover such matters as high energy solar proton emissions, atmospheric densities, ionospheric variations, the geomagnetic field, and particle fluxes in the radiation belts. All of these have a direct or indirect bearing on communications, surveillance and detection and on missile and aircraft operations.

The basis of space forecasting is a precise knowledge of the ambient space environment. Most of the work discussed in the foregoing sections of this Chapter, and in the following Chapter covering the work of AFCRL's Upper Atmosphere Physics Laboratory has relevance to space forecasting.

To tie all of this research together and to review it as a cohesive pattern, the Space Physics Laboratory, in January 1964, established a special organizational entity, the Space Forecasting

Branch. The function of the Branch is to evaluate and develop techniques for monitoring and predicting space environmental parameters. The Branch is divided into three subdivisions: 1) Space Forecasting Workshop to devise methods for making predictions, 2) an observing and monitoring section to develop techniques for the real time acquisition and use of data, and 3) a publication section which puts out a bulletin of pertinent data collected over each three-month period.

FORECASTING WORKSHOP: The Space Forecasting Workshop's primary task is to develop objective solar flare forecasting techniques for use by the Air Weather Service Solar Forecasting Center at Cheyenne Mountain, Colorado. The Solar Forecasting Center in turn makes daily forecasts of solar and geomagnetic activity in support of the various Air Force and DoD agencies.

One forecasting technique is through the statistical analysis of historical solar-geophysical data. In particular, the data for the ten-year period 1955–1964 (one solar cycle) are being exhaustively analyzed. These data include flares, sunspots, plages, radio emission, sudden ionospheric disturbances, and geomagnetic indices. The volume of data collected is enormous. There are over 80,000 flare reports alone. This collection is probably the most accurate and comprehensive set of solar-geophysical data available anywhere.

Multiple regression analysis of the various solar parameters is currently underway to pick out the best possible flare predictors. The final product of this analysis will be objective forecast equations that yield flare probabilities over specified time periods, given the latest quantitative values of the selected flare predictors. These equations can be handled by a computer for rapid real time use. As a first cut at a flare forecasting scheme, the Workshop developed a unique method for assessing the probability of occurrence of a solar flare "today," given just the sunspot area "yesterday" and "today." The forecast tables derived by this method are being used at the Solar Forecasting Center as part of their flare forecasting capability.

In the process of analyzing solar data from many sources, the Space Forecasting Workshop found a great need for standardizing the solar observing and reporting procedures. The discrepancies among reports have been intolerably large. Through coordination with key personnel at solar observatories all over the world, considerable progress has already been made towards standardizing the observing, reporting, and collecting of sunspot data. This standardization of observing procedures should eventually be extended to include all data types including flares, plages and radio emission.

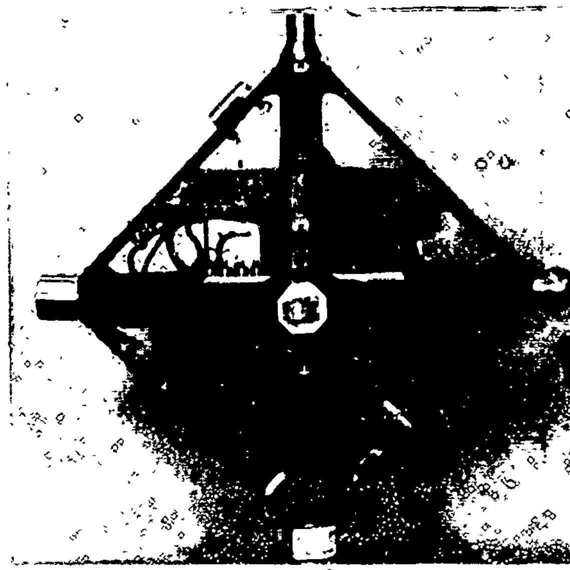
In the past, the main effort of this group has been concerned with the solar optical data. In January 1967, forecasting efforts were expanded to include density, ionospheric conditions, energetic particles, geomagnetism, solar radio and solar x-ray.

OBSERVING AND MONITORING: The observing and monitoring effort is concerned with the development of techniques for the acquisition and use of data in a real time mode of operation. To this end, a new facility, the AFCRL North Ipswich Telemetry Readout Station, was established.

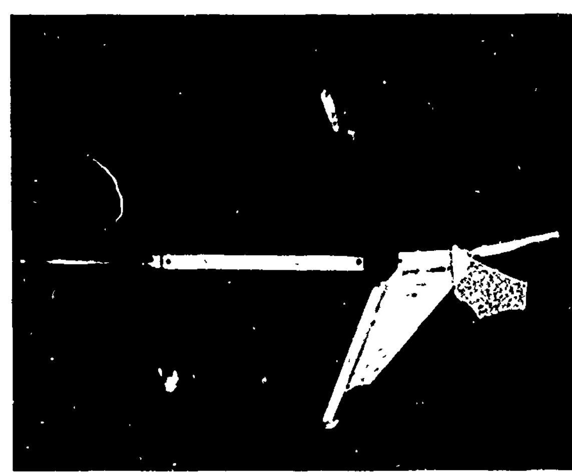
The station is equipped with a variety of antennas including a 60-foot dish, 12-foot dish, quad-helix, and quad-yagi antennas. The control building houses the associated receivers, tape recorders, strip chart recorders, time code generators, and so on. The first real operational

test of this facility took place with the launch of AFCRL's Solar X-ray Monitoring Satellite (OV5-1) on April 28, 1967 into a 4000 by 60,000 nautical mile orbit. The primary mission of this payload is to monitor soft x-rays (8–14 angstroms) and bremsstrahlung (20-100 keV) emanating from the sun, and to measure solar protons resulting from solar flares. This data will provide a basis for real time prediction of solar activity. The secondary mission of the payload is to measure energetic particles in space over a broad energy range of 1 MeV—80 MeV protons and .04—3.3 MeV electrons, thus providing additional data for the detailed mapping of the radiation belts and energetic solar particles.

The satellite transmits continuously when solar illuminated during its one-year intended lifetime. The transmitted data is received at the North Ipswich site and processed in real time. Information on significant changes in flux levels will be immediately transmitted to the Air Weather Service's Solar Forecasting Center.



The OV5-1 satellite (shown above with solar cell panels removed) was launched on April 28, 1967 into a 7,400 by 111,000 km orbit and was designed to monitor solar x-rays and solar protons resulting from solar flares.



PUBLICATIONS: The *Geophysics and Space Data Bulletin* is a quarterly publication presenting AFCRL contract and in-house geophysics and space data from many separate programs reported from more than 25 sites throughout the world. These quarterly reports (containing continuous data beginning January 1, 1964) are distributed to more than 900 scientists. The Bulletin contains data on geomagnetic field variations, cosmic ray intensity, solar flares and other chromospheric activity, sunspot activity, spectrographic coronal observations, solar radio emission, and vertical incidence and oblique backscatter ionospheric soundings.

In addition, a four color 30 by 40 inch wall chart entitled "Aerospace Environment" was prepared and distributed to the scientific community. The chart provides a convenient summary of some of the latest available information on the aerospace environment gathered by AFCRL sensors, and those of other environmental research laboratories.

ENERGETICS RESEARCH

Energetics is the study of energy sources and the analysis of the processes by which this energy can be converted from one form to another. Optical, thermal and chemical energy sources are the principal AFCRL interests. Energy conversion processes which result in usable electrical power receive major emphasis. The AFCRL program is primarily concerned with the understanding of the fundamental physics and chemistry of energy conversion processes. But when the research indicates the possibility of a novel or improved energy conversion technique, rudimentary devices are fabricated for evaluation. This program bears directly on Air Force needs for specialized power sources and improved power generation systems.

This AFCRL effort has four separate parts: 1) *quantum processes:* the study of photoconducting and semiconducting materials for converting solar energy to electrical energy; 2) *thermal processes:* analysis of techniques for obtaining power from thermal energy sources; 3) *photochemistry.* research on photosynthetic processes and their potential use in fuel cells, and 4) *electrochemistry:* the study of the factors which control electrode characteristics in fuel cells and batteries, and analysis of the chemical parameters affecting battery efficiency and lifetime.

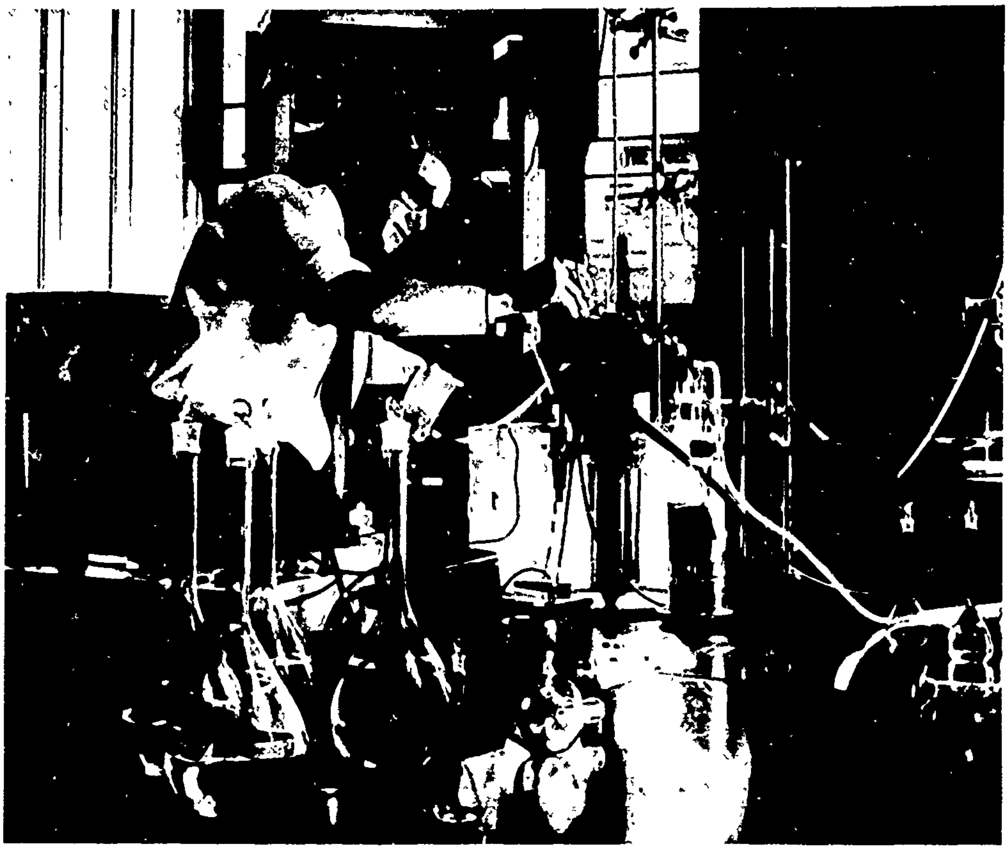
QUANTUM PROCESSES: Perhaps the most widely known example of a quantum process device is the solar cell currently in use as a power supply in satellites and other space vehicles. The solar cells presently used for satellite power are inorganic semiconductors—the photoconducting material being silicon.

AFCRL is investigating the energy converting properties of organic materials as well as inorganic materials. This work has resulted in significant advances in the efficiency of organic materials as energy sources. But the power output of present organic cells is well below that of conventional inorganic devices.

In certain applications, however, organic cells have distinct advantages. Most important of these is that they can be fabricated to respond to distinct wavelengths in the visible or near-infrared region. Extremely sensitive cells have been built with response times of microseconds. Thus they have potential application as sensors in research instrumentation. Other advantages are their low cost and weight and the fact that they can be fabricated in a variety of structural configurations. Primary disadvantages are high electrical resistance and a tendency to decompose under conditions of high temperatures or radiation fluxes. Methods of fabricating organic and inorganic cells are similar.

AFCRL investigations involve both photoconductive and non-photoconductive organic materials. With these materials, two types of thin film cells are fabricated. The simpler type is formed by first depositing aluminum electrodes by high vacuum sublimation on a Pyrex glass plate. A photoconductive organic compound and a second electrode of gold are deposited in turn on the aluminum electrode. The second type is fabricated in a similar manner, but instead of a single layer of photoconductive material, adjacent layers of photoconductive and non-photoconductive materials are sandwiched between the aluminum and gold electrodes.

The Laboratory has fabricated some 13 organic photovoltaic cells of both types but with a range of different photoconductive and non-photoconductive



Energetics research has a large chemistry research component. The AFCRL program is concerned with the fundamental physics and chemistry of energy mechanisms.

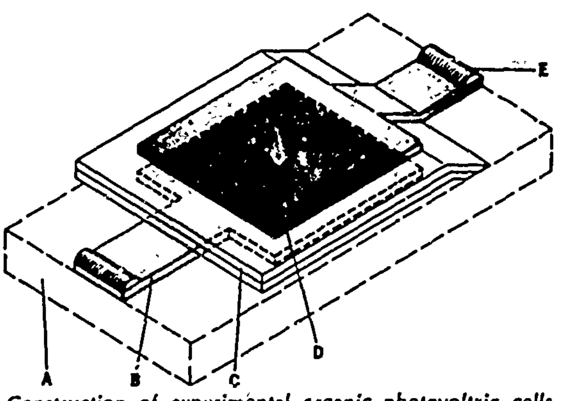
materials in various combinations. The two layer system, in which the nonphotoconductive layer is an electron acceptor, has given the best power output in experiments to date. Power has not exceeded three microwatts; photocurrent has not exceeded four microamperes, and is typically about one microampere.

THERMAL PROCESSES: The main Laboratory emphasis in the area of thermal processes is the thermionic energy converter in which a heat source is used to "boil off" electrons from a metal emitter. Electrons then flow under vacuum to an electron collector possessing a lower work function than the emitter. This electron flow provides a current which can do useful electrical work. In addition to work on the surface structure of emitter and collector metals, AFCRL scientists have deduced the existence of a hitherto unsuspected volume force which may be significant to the understanding of electron beam plasmas. This force is a pressure on neutral gas atoms (such as cessium atoms used to reduce space-charge effects in thermionic converters) caused principally by the electrophoretic effects of electrons between biased electrodes. This phenomenon may provide some insight into

plasma behavior and may be exploited to increase the efficiency of thermal energy conversion systems.

PHOTOCHEMISTRY: Photosynthetic processes command the interest of energy conversion researchers because of the high efficiency of photosynthesis. AFCRL is seeking to explain the mechanism whereby plants and primitive living systems such as algae store the sun's energy for subsequent use, the essential first step toward the exploitation of these energy-rich systems.

The study of various combinations of chlorophyll with compounds such as hydroquinone has led to a prototype photovoltaic cell. Various other chemicals such as triethylamine and dimethylformamide have been found capable of enhancing this photovoltaic effect. An attempt to separate and classify the various subunits which constitute the chloroplast is expected to shed light on the identity of the active components responsible for photovoltaic enhancement. AFCRL's basic studies on the chemical and physical changes occurring in macromolecular systems as a function of the wavelength of incident radiation furnish data for detailed analysis of the photosynthetic process and its application to specialized energy conversion systems.



Construction of experimental organic photovoltaic cells developed at AFCRL: (A) glass plate, (B) aluminum back electrode, (C) single or double layer of organic material, (D) gold front electrode, (E) silver paste contact.

Design details of an AFCRL developed organic photovoltaic cell is shown. The unique device has a high resistance to thermal and radiation damage.

ELECTROCHEMISTRY: Fuel cells and batteries, and the processes that limit their performance, are the primary concerns of the Laboratory's electrochemistry efforts. Under study are such performance-limiting factors as the absorption of foreign ionic and neutral species on the active sites of electrodes, the hitherto unsuspected effects of minute impurities in solvents on battery performance and the interaction of alkali metals and non-aqueous solvents in high-energy density batteries.

From this program has come a novel self-regenerative photoelectrochemical cell. Early evaluation of this cell, developed by Laboratory scientists in 1966, has shown it to be a highly promising device. The key element of the cell is a silver electrode coated with silver chloride. In a cyclic oxidation and reduction process, light oxidizes the silver chloride photochemically. When a current is passed through an external load, electrochemical reduction of the silver chloride takes place. Basically, the cell consists of a sealed transparent container into which is placed the silver chloride covered silver electrode and a platinum electrode. A potassium chloride electrolyte provides a conductivity path across the electrodes. Oxidation is induced by light passing through the transparent container of the self-regenerative cell.

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IV Upper Atmosphere Physics Laboratory

Upper Atmosphere Physics Laboratory scientists conduct research on the physical and chemical properties of the earth's atmosphere from the lowest level of the ionosphere, just above the stratosphere at about 50 km, out to several earth radii where the earth's atmosphere merges with interplanetary space.

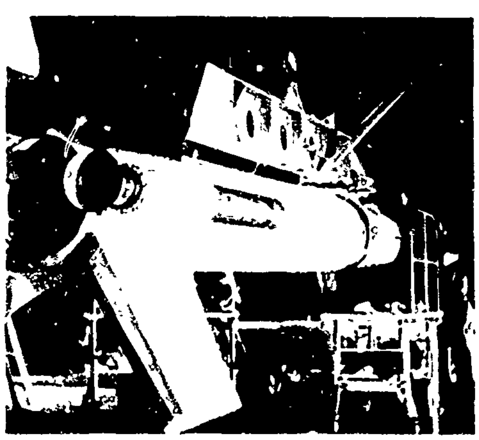
The Laboratory's interests are many: upper atmosphere densities, pressures and temperatures; composition of atmospheric gases, airglow and the aurora; physical and chemical processes; the solar ultraviolet radiations that impinge on the earth's atmosphere to initiate many of the dynamic chemical processes, and the propagation of electromagnetic waves through this region.

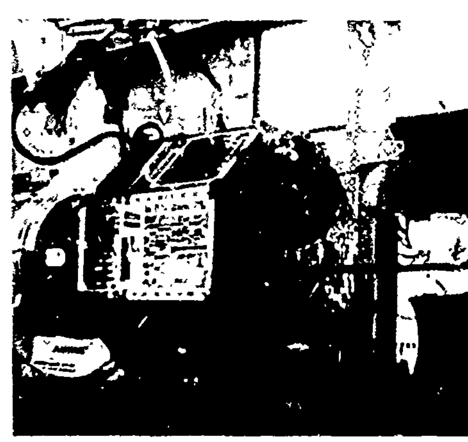
The free electrons and ions found throughout this region specify the performance capability of most radio communications and govern the parameters of surveillance radars. The visible emissions over the sky at night resulting from the recombination of atoms and molecules set the threshold of sensitivity for optical reconnaissance equipment. And the densities and temperatures in this region are factors in the design and performance of aerospace vehicles.

A multiplicity of methods are used in these upper atmosphere studies. Many measurements such as the observation of airglow and auroral phenomena and the probing of the ionosphere by ground-based transmitters and receivers are made from the ground. A variety of equipment is carried aboard a KC-135 aircraft thus making possible wide geographical coverage of upper atmosphere

characteristics and phenomena. But there are certain properties of the upper atmosphere that cannot be measured except by placing instruments directly in the upper atmosphere environment. In the region between about 50 to 200 km, sounding rockets are the only vehicles that can gain easy access. The Upper Atmosphere Physics Laboratory is the largest single AFCRL user of sounding rockets—some 66 of the AFCRL total of 104 launched during the two years of this report. For studies above 200 km, during the same period, scientists from this Laboratory placed packages aboard eight different Air Force and NASA satellites.

This Laboratory, historically, has been one of the largest (most likely, the single largest) contributors in the world to the knowledge of the structure of the upper atmosphere. Such contributions are manifested in hundreds of papers in the scientific literature. But scientific papers have come more and more to have a transient quality and in the aggregate





To measure upper atmosphere densities, temperatures and dynamics, the Upper Atmosphere Physics Laboratory uses instrumented balloons, KC-135 aircraft, rockets and satellites.

do not make for ready reference. For this reason, AFCRL has contributed strongly to handbooks and reference documents on the upper atmosphere, three of which were issued during this period. Two of these grew out of large multi-agency efforts, with the basic data derived from all available national and international sources. These two are the "COSPAR International Reference Atmosphere 1965" and the "U. S. Standard Atmosphere Supplements, 1966." The third, "Handbook of Geophysics," was prepared solely by AFCRL and published by McGraw-Hill.

The "COSPAR Reference Atmosphere 1965" was published by the North-Holland Publishing Company. The major AFCRL contributions were Part One, "Mean Atmospheric Structure in the Region from 30 to 300 km," and an Appendix entitled "Atmospheric Structure in the Lower Thermosphere."

The "U. S. Standard Atmosphere Supplements, 1966," published under the auspices of the U. S. Committee on the Extension of the Standard Atmosphere (COESA), consists of models of the atmosphere from the ground level up to 1000 km. Up to 120 km the variables are season and latitude. Above that latitude the models are also functions of solar flux, time of day, magnetic indices and other parameters. This volume is a companion volume to the "U. S. Standard Atmosphere, 1962." Both the Upper Atmosphere Physics Laboratory and the Aerospace Instrumentation Laboratory were heavy contributors to this volume which is discussed in somewhat more detail in the following chapter, Chapter V.

PHYSICAL STRUCTURE

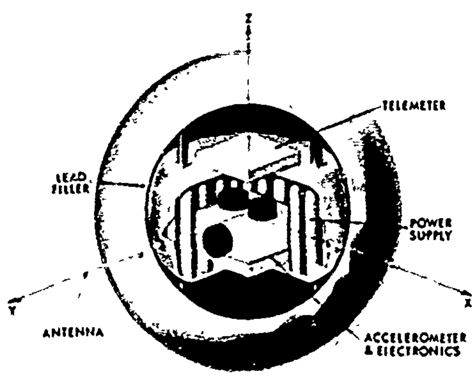
Physical structure of the upper atmosphere can mean many things, but for purposes here it is defined in terms of densities (or pressures), temperatures and winds. Included in the definition are wind shears, diffusion constants, and atmospheric turbulence. Many of these values are strongly interrelated. From a knowledge of temperature, for example, it is often possible to derive density, and from density, temperatures.

Density and temperature are only two of many upper atmosphere parameters. Although they are treated somewhat in isolation from other parameters in this section, the total cause-and-effect interrelationships that sustain upper atmospere dynamic processes are inordinately complex. An understanding of upper atmosphere dynamics leading to meaningful mathematical descriptions must take into account solar ultraviolet radiations, composition, associative-dissociative mechanisms, electrical structure and so on, all of which are discussed in later sections.

The structure of the upper atmosphere is in continuous process of change, and this change varies widely in space and time. From this, it may be correctly inferred that the three reference documents noted in the introductory section of this chapter represent compilations of typical values. The values assigned to atmospheric parameters in the basic reference documents undergo continuous refinement as instruments of increasing sophistication and variety are developed and sent aboard rockets into the upper atmosphere. The variety of approaches for measuring just one atmospheric parameter—that of density—is pointed up in the individual studies discussed in the following paragraphs.

SATELLITE ORBITAL DECAY: Density data can be derived by plotting satellite trajectories and orbital decay. With the

During the period, Dr. Kenneth Champion designed the density measuring satellite illustrated below. It has a diameter of only 20 inches and weighs 600 pounds. The high weight-to-size ratio will permit the satellite to remain in orbit with a perigee as low as 120 km.



very first satellite, methods were formulated for obtaining such data. But the early programs lacked mathematical rigor, and the validity of results were further degraded by unknown variables such as the effects of the earth's external gravity field and of the varying aspects which non-spherical tumbling satellites presented to the direction of forward motion.

Since then, drag effect studies have increased in precision. One such program by AFCRL involves numerical integration of the basic equations of motion for application to certain satellites in low orbit or during reentry phase. The program was used to calculate atmospheric densities from observations of several satellites, including the Italian satellite San Marco I and Explorer XVII.

The satellites used were not, of course, specifically designed to provide density data. During the report period, AFCRL scientists undertook the design of a satellite having the sole purpose of providing density data based on the drag on the satellite by the upper atmosphere. The satellite is characterized by its high weight-to-size ratio. When launched in the spring of 1968, the satellite will provide the most precise information to date on atmospheric densities in the region between about 130 and 400 km.

The small spherical satellite will have a diameter of only 20 inches and will weigh 600 pounds. To increase mass, lead filler will be added to the structural shell. The satellite will have a mass as high as six grams per cubic centimeter, five times that of the average satellite.

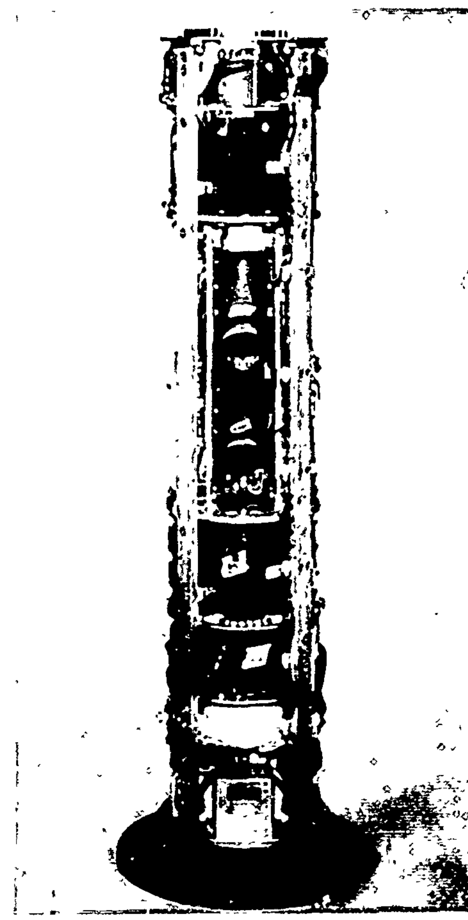
The perigee will be the lowest of any satellite launched to date—about 120 km—which will take it relatively deep into the earth's atmosphere. The mass of the satellite (and its smooth spherical exterior) will reduce the effects of atmospheric drag permitting it to remain in orbit for an extended period in spite of its low perigee.

The satellite will contain a triaxial accelerometer, appropriate electronics,

power supply, telemetry transmitter, radar beacon, and antennas. The accelerometer will enable density measurements to be made with considerable resolution in space and time. Radar tracking of the satellite will enable density to be deduced from orbital observations. This will provide both a back-up and a means of checking the calibration of the direct reading instrumentation.

Of particular interest to upper atmosphere scientists are short-term fluctuations in atmospheric density. Weather patterns, analogous to those experienced at ground level, exist at satellite altitudes. In these patterns, pressure, density and temperature vary with altitude, longitude and time.

SNAP 10A SATELLITE MEASUREMENTS: Direct density measurements were made at altitudes near 1300 km with an ionization gauge on the SNAP 10A satellite launched in April 1965. The polar orbit of the vehicle permitted observations of density variations over a complete range of latitudes. Density variations with latitude, on both day and night sides of the earth, were recorded during a number of orbits. The sensor, a newly developed hot-filament magnetron gauge first used on the satellite, provided the lowest direct measurements of atmospheric density yet obtained. The results show that the diurnal density variation near 1300 km is less than that predicted by present model atmospheres. This result is in agreement with measurements made by others on drag effects on high altitude satellites.



The Bremsstrahlung technique for measuring atmospheric densities consists of firing an electron beam (from the two electron guns shown in the center of this rocket payload) into the surrounding atmosphere. Collisions of these electrons with atmospheric molecules produce x-rays which are detected by instruments aboard the rocket.

ROCKET DENSITY MEASUREMENTS: Three techniques for obtaining extremely precise data on atmospheric densities by rockets are under study. These separate techniques involve falling spheres, the Bremsstrahlung effect, and Rayleigh scattering.

The first of these techniques, now well established, is one in which a rigid sphere is released from a rocket during its ascent. The rigid sphere, measuring seven inches in diameter, contains an accelerometer and a transmitter for telemetering drag acceleration information

to the ground. Improved accelerometers for this system have extended the lower limit of sensitivity to below $3x10^{-5}g$. Overall performance has qualified the system as a proven instrument for measurements of neutral atmospheric properties. During the period covered by this report, 15 falling sphere rocket flights were made from Eglin AFB, White Sands Missile Range and Fort Churchill. Atmospheric densities were calculated from the measured values of drag acceleration, and temperatures and pressures were deduced in turn from these results. The Eglin and White Sands data agreed well with established models for 30 degrees latitude. Measurements at Churchill in the winter months uncovered an unsuspected fine structure of fluctuations in densities which appear to correlate with the moderately high geomagnetic activity existing at the time of the measurements. The fluctuations in density seem to be the result of magnetic concentration of corpuscular radiation in polar regions.

The Bremsstrahlung technique consists of firing a beam of high energy electrons from an electron gun into the surrounding atmosphere. The Bremsstrahlung radiation emitted by the electrons as they are slowed down by collisions with atoms and molecules is measured by an x-ray detector in the rocket. This technique is useful for density measurements up to about 200 km. Following a long period of Laboratory tests in which a vacuum chamber was used to check out systems concepts, a rocket flight test was first made at Eglin AFB on March 10, 1966. The system itself performed satisfactorily, but a number of additional flights are planned before the full merit of the technique for measuring densities can be established.

A still later technique for measuring atmospheric density by rocket instrumentation is one exploiting the scattering of light—Rayleigh scattering. Most of AFCRL's work to date has been confined to Laboratory analysis of the potential of the system. By the end of the reporting period, the program had progressed to the point of rocket payload design. Rayleigh scattering by the principal atmospheric constituents (N_2, O_2 and O) in the altitude range of 80 to 300 km has been calculated. To measure density by this method, it is necessary to know the extent to which each of the atmospheric constituents scatters light. This has been determined for the oxygen atom. Normal and slant optical thicknesses as a function of altitude were also calculated. If the program proceeds on schedule, the first rocket tests for measuring atmospheric density by Rayleigh scattering will be made late in 1967.

Other density measurement techniques using rockets are covered in Chapter V. The distinction between the techniques under investigation by the Upper Atmosphere Physics Laboratory and those by the Aerospace Instrumentation Laboratory lies in purposes and application—and in the altitude regime of interest. The motivation of the upper atmosphere physicist is in gaining a better understanding of fundamental dynamics. The density measurement programs to be covered in the following chapter are designed to provide the meteorologist with density measuring equipments that might have a bearing on day-to-day weather forecasting, or that might be used by the Air Force in operational situations.

SURVEY OF CHEMICAL RELEASE PROGRAM: Some structural features of the upper atmosphere are made strikingly visible by the simple expedient of releasing a luminous chemical trail along a 150 km vertical path by rocket. Camera observations of this trail from the

ground show the influence of winds, wind shears, and atmospheric turbulence. With other kinds of instruments and analysis, diffusion constants, atmospheric density and temperature can be measured. By releasing various chemicals, it is possible to derive additional information on such atmospheric properties as the concentration of oxygen atoms in the atmosphere, and the alignment of ionized regions along magnetic field lines.

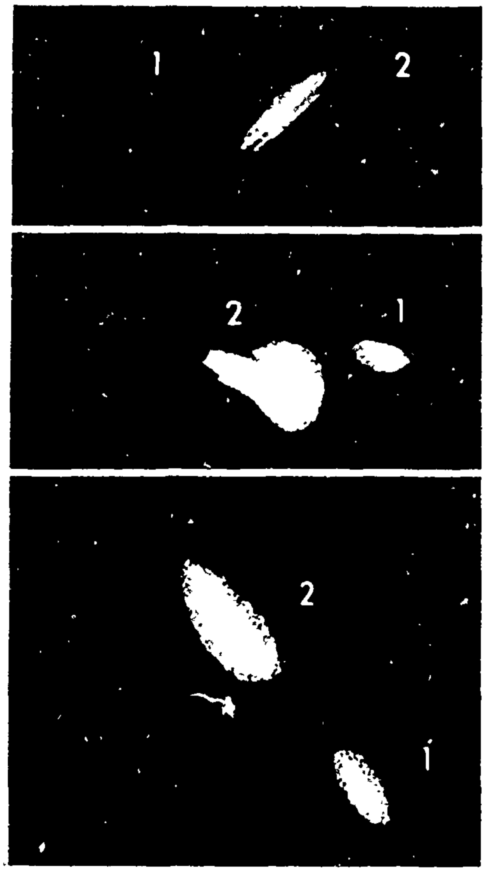
AFCRL launches more rockets under its chemical release program than under any other single program. During the two-year period of this report, 46 rockets were launched containing a variety of chemicals for release in the upper atmosphere. Often a particular investigation will require the multiple launch of rockets at scheduled intervals over a 24-hour period. In May of 1966 for example, 19 rockets were launched in a single day from Eglin AFB, Florida. Altitudes at which chemical releases are most effective are between about 80 and 250 km. Although research groups all over the world have used the chemical release method since the first experiments in 1955, the technique was pioneered by AFCRL and AFCRL remains the single most active user of the technique.

Between 80 and 200 km where most investigations take place, density falls from 10^{-5} to 10^{-10} of sea level density. At sea level, a single cubic kilometer contains a million tons of air, but at an altitude of 150 km, the mass of air in a cubic kilometer totals less than two kilograms. Thus, a kilogram of chemical released at this altitude will make up a sizable portion of the total gas in the injection zone, and can grossly modify the chemistry in this zone. After release, the gas expands radially without intermixing, forming a "bubble" until its pressure falls to that of the surrounding air. Depending on altitude, the bubble radius may range from meters to kilometers. The expansion to ambient pressure requires only a fraction of a second, the time required for a molecule at thermal velocity to travel a distance equal to the bubble radius.

Most AFCRL rockets are fired from Eglin AFB, Florida, which provides considerable technical help. Here Dr. Norman Rosenberg (center left) of AFCRL meets with Eglin personnel who will assist in the rocket launch.

Different chemicals are released for different types of studies. Some chemicals absorb free electrons or ions and thus deplete an ionized region of charged particles leaving electron-free holes in the ionosphere. Other chemicals such as cesium are used to increase electron density, forming dense artificial electron clouds. Among the chemicals used are sodium, trimethylaluminum, cesium, barium, aluminum oxide and nitric oxide.

In the previous reporting period, a number of programs were discussed—the creation of dense electron clouds to provide a reflector for electromagnetic



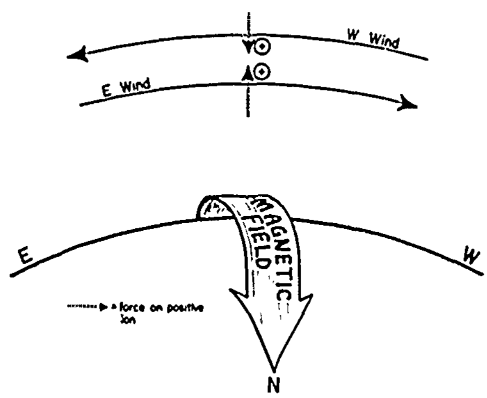
The same barium chemical cloud was photographed 100 km west, north and east of the launch site 10 minutes after release. The cloud labeled No. 1 in each photograph is at 150 km; the cloud labeled No. 2 is at 190 km. In the top photo, note the striations created by the earth's magnetic field lines.

radiation for over-the-horizon communications, the detonation of an explosive charge to induce shock waves in the chemical trail in order to derive density and temperature data based on characteristics of the resultant shock wave, and the evaluation of turbulences created by missiles passing through the upper atmosphere by studying the effects on chemical trails at varying distances from the missile trajectory. Many of these studies continued during the present period, but new lines of investigations were also undertaken.

ARECIBO AND CHEMICAL RELEASES: Of the 46 rockets fired under the chemical release program in the period July 1965–June 1967, all but four were launched from Eglin AFB, Florida. These four were launched from Camp Tortuquero, Puerto Rico, in February 1966 near the Arecibo radio telescope.

The program was a cooperative one between Cornell scientists operating the Arecibo facility and AFCRL. It had several aspects. One was to determine whether or not electron layers and irregularities moved with and at the same velocities as the neutral wind. These electron layers and irregularities when observed from the ground by radio means seemed to move with considerable velocity. Is this observed velocity real or are the observed velocities the result of phase velocities of wave motions? Because a chemical trail is primarily influenced by the neutral winds, it is possible, by simultaneous radio observations of electron irregularities and camera observations of movements in the chemical trail to determine whether the electron irregularity movement and the neutral wind movement are the same. The results showed that in general they were the same.

Still another aspect of the Arecibo-AFCRL study had to do with a theory put forth several years ago by AFCRL. This theory relates to a possible mechanism whereby electron irregularities and, in particular, sporadic E are formed. This theory predicts that charged particles in the low ionosphere will be forced to pile up into thin layers due to the fact that the particles are moving relative to the earth's magnetic field. The magnetic field deflects the par-



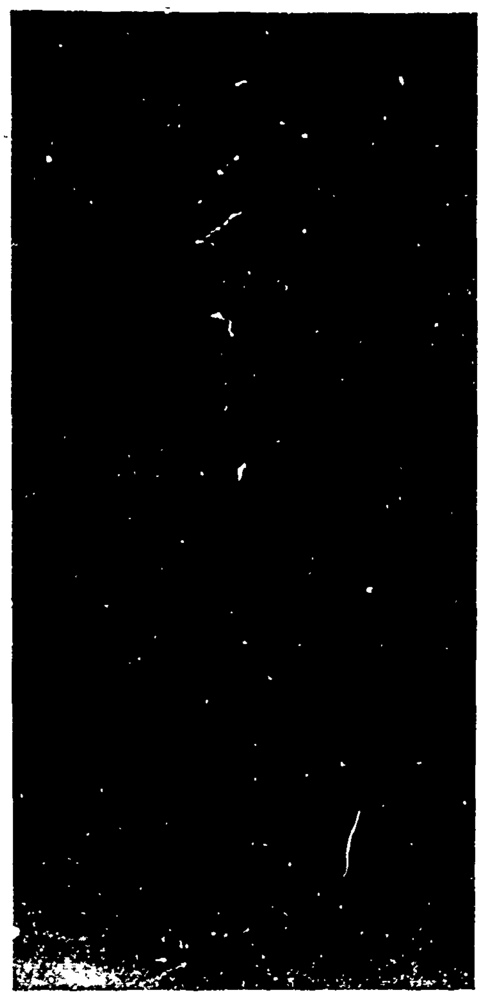
Electrons transported by the wind will be forced up or down depending on their direction relative to the earth's magnetic field. AFCRL theory predicts that electrons will thus be compressed into thin layers, creating irregular electron patches known as sporadic E.

ticles vertically, with the amount of deflection depending on the direction and velocity of the wind at any given altitude. Because the 160 to 250 km per hour wind changes direction by 180 degrees roughly at 25 km intervals, the 150 km long luminescent trail produced by the rockets will be distorted and will assume a helical configuration. Thus, the moving charged particles cut across the lines of force of the earth's magnetic field at all angles, and are deflected more strongly at given altitudes. This causes them to pile up at certain altitudes, thereby, according to theory, creating sporadic E and other electron irregularities. The results of the experiment strongly supported AFCRL's wind shear theory.

One important potential consequence of the study is the possibility of measuring neutral wind velocities and directions in the upper atmosphere by ground-based radio observations alone because of the relationship between the movements of electron irregularities and neutral winds.

OTHER CHEMICAL RELEASE EXPERIMENTS: The following paragraphs cover a number of separate studies under the chemical release program—studies that illustrate the usefulness of the release technique in illuminating many diverse properties of the upper atmosphere.

If it is assumed that the chemical, once released into the upper atmosphere, quickly reaches thermal equilibrium

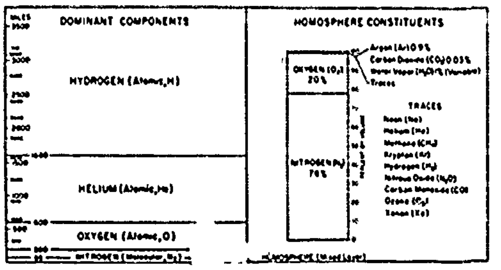


The effect of winds on a smoke trail 30 km in vertical length is clearly shown in this photograph.

with the ambient, then temperatures can be calculated from the fluorescent spectrum of certain chemicals. This is possible because the relative intensities of various molecular resonance bands are proportional to temperature. Aluminum oxide (AlO) is the primary chemical used for such temperature measurements. Typical results are these (derived during evening twilight at summer and at a latitude of 30 degrees N): 450 degrees K at 125 km, 650 degrees K at 150 km and 700 degrees K at 165 km. From these same chemical trail experiments used to calculate temperature, it is possible to deduce diffusion coefficients by observing chemical trail expansion. In the evening twilight at 150 km, for example, it was found that these coefficients are approximately twice as large as in the morning, being 4×10^8 cm^2 sec^{-1} and 2×10^8 cm^2 sec^{-1}, respectively.

In another experiment to obtain atomic oxygen concentration profiles in the 90 to 140 km region, nitric oxide trails were used. Atomic oxygen can be measured because the intensity of the resultant glow of the trail is directly proportional to the concentration of atomic oxygen. It was found that peak concentrations of 10^{11} atoms cm^{-3} occur between 103 and 107 km. The profile rises sharply from above 90 km and decays more slowly above 110 km. The study of atmospheric oxygen is important because of the large role oxygen has in photochemical and chemi-ionization phenomena in the atmosphere.

In a series of relatively low altitude —30 to 80 km—releases it was found that the wind structure in this region is more complex than could be inferred from soundings with a falling sphere or other techniques which tend to average out features with vertical scales of less than a kilometer.



The mixture of gases that make up the lower atmosphere is fairly constant below about 105 km. Above that altitude nitrogen, oxygen, helium and hydrogen each in turn become the dominant components.

CHEMISTRY AND ELECTRICAL STRUCTURE

This section will share the view of the physical chemist. The physical chemist sees the upper atmosphere in terms of the dissociation, attachment and recombination of atoms and molecules. He is concerned with the concentrations of atmospheric species at various altitudes and with how these species interact. His view is on a microscale level. The electrons, atoms, ions and molecules of the upper atmosphere and magnetosphere and their transformations and transport are of basic interest. Transformation and transport are, in fact, the characteristic attributes of the gases comprising the upper atmosphere. Knowledge of variations in charged particle distribution as a function of time, altitude, latitude, longitude, and solar and magnetic conditions is essential to an ultimate formulation of a mathematical characterization of the total structure of the upper atmosphere.

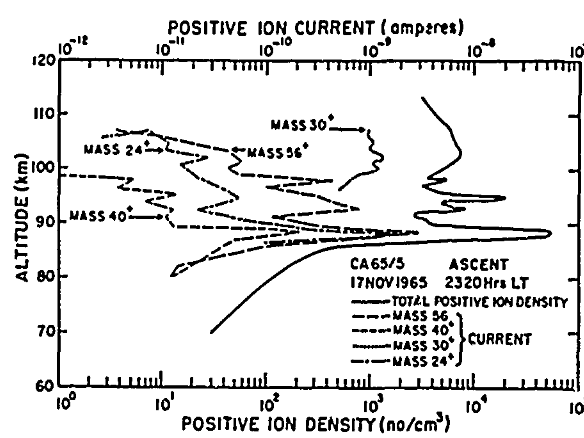
The elaborate chemistry of association and dissociation of molecules, ions and electrons results in the continuous creation and dissipation of the ionosphere. But the ions and electrons that

make up the ionosphere, even where they are most heavily concentrated, are only a small fraction of the neutral atmosheric constituents. The electron density at the highest point of concentration at about 200 km is only about 10^6 per cubic cm—one-thousandth the neutral particle number at the same altitude.

The most precise and direct way to measure the neutral and charged particle composition of the upper atmosphere is by placing instrumentation aboard a balloon, rocket or satellite vehicle. During the two years covered in this report, a total of 19 mass spectrometer systems of several varieties were flown on rocket and satellite vehicles to measure neutral and ionic constituents from 60 to 1600 km. Laboratory instrumentation to detect charged particles was flown on six different satellites and scores of research rockets. Of the instrumentation aboard satellites, sensors incorporated on the Gemini 10 and Gemini 12 vehicles were of particular interest. These sensors were a part of an AFCRL satellite attitude control system. The system was flown to test it against the spacecraft's inertial attitude control system. This AFCRL system evolved directly from scientific instrumentation initially designed by AFCRL to measure the electrical properties of the upper atmosphere.

METALLIC IONS FROM METEOR SHOWERS: During the annual Leonid meteor shower in November 1965, two Nike-Cajun rockets carrying unique cryogenically pumped mass spectrometers to sample the positive ion composition of the D and lower E regions of the ionosphere were flown, one at noon, the other at midnight. The daytime results represented the first measurements of the effects of a meteor shower on the lower ionosphere. It is in these regions, which extend from about 60 to 110 km, that atmospheric friction heats and vaporizes meteorites. Metallic ions of meteoric origin were found to make up a sizable portion of the content of the lower ionosphere. Between 82 to 100 km, the positive ions of sodium, magnesium, aluminum, calcium, iron, nickel and silicon—all substances found in meteorites—were seen to constitute 30 to 60 percent of the total ionization (the remainder being the normal atmospheric ions of nitric oxide and molecular oxygen). The metal ion concentrations were found to be much lower between 100 and 110 km, the altitude immediately above that where maximum meteor vaporization occurs.

It is interesting to note that although a large percentage of metal ions were detected, the total charged particle concentrations showed little change from non-shower conditions because the molecular ions of nitric oxide and oxygen correspondingly decreased through recombination with the extra electrons contributed by the metal ion plasma. The reason for this is that the lifetime

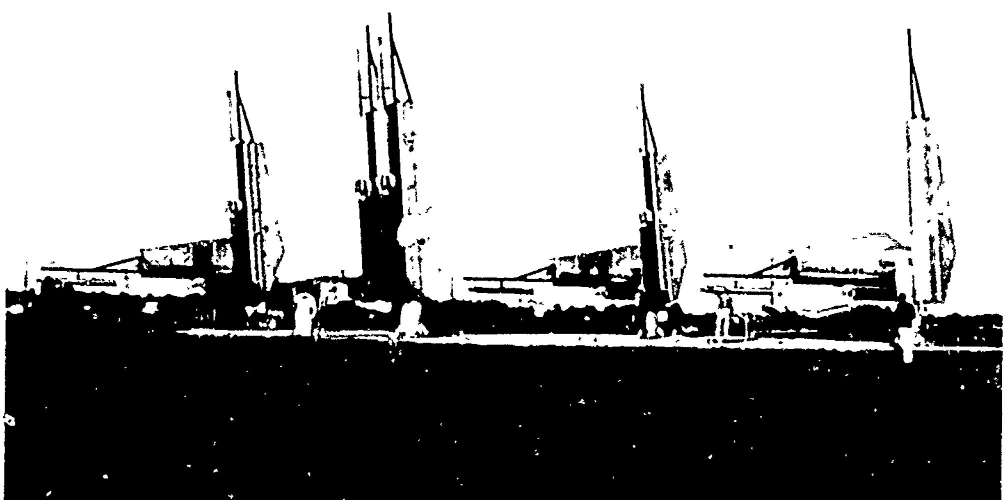


AFCRL rocket experiments have uncovered a heavy region of metallic ions between 82 and 100 km. Shown here are some of these ions in relation to the total ion density.

before electron recombination of a molecular ion is much shorter than that of an atomic metal ion.

On the nighttime rocket flight, the first composition measurements of mid-latitude sporadic E layers were made. These highly localized layers of increased electron and ion density, varying in thickness from a fraction of a kilometer to three to five km, occur at unpredictable times and are known to have a pronounced effect on radio communications. The rocket measurements showed that these layers were composed entirely of the positive ions of iron, magnesium, calcium, and nickel, listed in order of decreasing abundance. These measurements corroborate current theories on the layering mechanisms which indicate that the ions must be long-lived (as the metal ions are) to create dense ionization layers.

NOVEMBER 12, 1966 SOLAR ECLIPSE: Photochemical processes in the upper atmosphere undergo a marked and dramatic change during a solar eclipse when the ionizing radiation from the sun is screened by the moon. Detailed measurements in the D and E regions of the ionosphere by rocket-borne experiments during the eclipse are especially revealing of reaction rates. Through observations of time constants during the

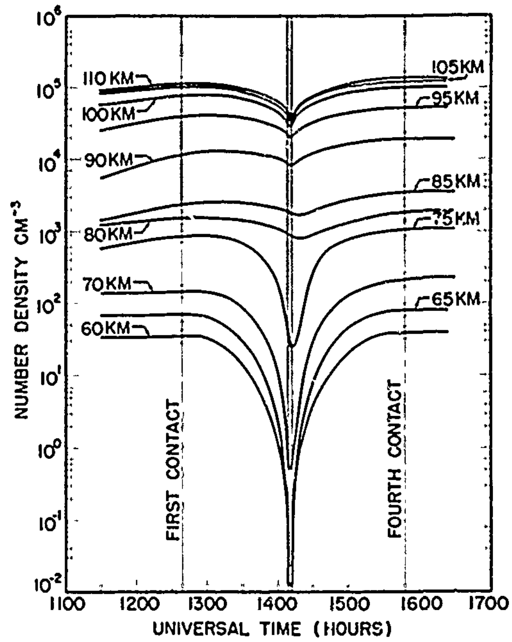


To observe the solar eclipse of November 12, 1966, from Rio Grande, Brazil, AFCRL instrumented four of the seven Nike-Hydac rockets shown here ready for launch. Instruments included a mass spectrometer, ion trap, RF impedance probe and Geiger counters.

short-lived event, information can be gained about attachment and detachment processes and about recombination processes in this region of the ionosphere.

The Laboratory conducted a joint rocket program with other United States agencies during the November 12 solar eclipse in Brazil. A rocket complex was constructed on the Atlantic Ocean about ten miles south of the city of Rio Grande by American and Brazilian engineers. Of the 16 rockets fired by the United States, the Laboratory instrumented four Nike Hydac rockets. Instruments included an ion mass spectrometer, an ion trap, an RF impedance probe, a retarding potential analyzer, Geiger counters, and a Lyman-Alpha ionization chamber.

One rocket was flown one week prior to the eclipse to provide reference background measurements and to certify the payload. The three eclipse rockets, fired at 12-minute intervals, were designed to reach an altitude of 115 km. The first and third rockets were fired so that the sun was 80 percent obscured when the rocket was ascending. The second rocket was fired so that the rocket was ascending at totality. Successful measurements were made of ion masses, ion densities, electron densities, solar x-rays and Lyman-Alpha flux. These were the first measurements of the change in the composition of the lower ionosphere during a solar eclipse. The normal daytime ion composition at 30 degrees south latitude was found to be most similar to that at 30 degrees north latitude. In the range 60 to 82 km, the water cluster ions H_3O^+, $H_5O_2^+$ and $H_7O_3^+$ were detected and again found to decrease sharply around the mesopause (about 82 km). Above 82 km the metal atom ions, predominantly iron and magnesium, were found to be in layers similar to those found in the Northern Hemisphere. The



Electron densities at various levels of the upper atmosphere are dramatically decreased during the brief period of a solar eclipse at all altitudes between 60 and 120 km.

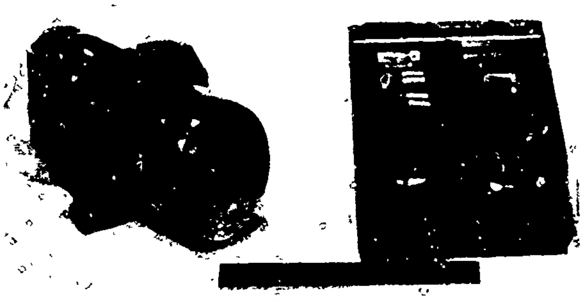
most abundant species above 82 km were the ions of NO^+ and O_2^+. Measurements made during the total eclipse of the sun showed little change in the metal ion abundances, while NO^+ and O_2^+ decreased significantly, as expected, on account of the shorter lifetimes of the molecular ions.

ION MOLECULE REACTIONS: The frequent observation of the water cluster ions H_3O^+, $H_5O_2^+$, and $H_7O_3^+$ in rocket-borne mass spectrometers led AFCRL to investigate the production of these species by ion-molecule reactions. A rate constant of 8×10^{-10} cm^3 molec.$^{-1}$ sec.$^{-1}$ was obtained for the formation of H_3O^+ by reaction between H_2O^+ and H_2O, in good agreement with similar studies made elsewhere. The formation of $H_5O^+_2$ in a three-body reaction between H_3O^+ and H_2O was found to have a rate con-

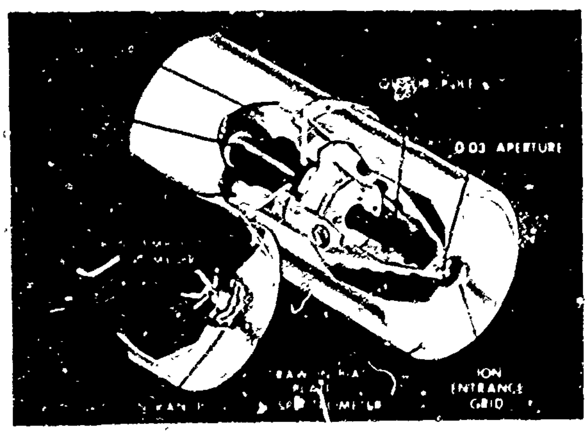
stant of 7×10^{-28} cm^6 molec.$^{-2}$ sec.$^{-1}$ with N_2 as third body and 11×10^{-28} cm^6 molec.$^{-2}$ sec.$^{-1}$ with H_2O as third body. The ions $H_7O^+_3$ and $H_9O^+_4$ were also observed arising from three-body reactions of $H_5O^+_2$ and of $H_7O^+_3$ respectively, with two molecules of water. The rate constants for these processes are estimated to be three to four times larger than that for the formation of $H_5O^+_2$ when H_2O is the third body.

The reactions of negative ions with neutral species are believed to be important in the D region of the ionosphere. Rate constants for reactions of O^- ions with O_2, NO_2, and N_2O were obtained. By the use of isotopically labeled oxygen, it was shown that in the endothermic reaction $O^- + O_2 \rightarrow O^-_2 + O$ the probability of simple charge transfer is about three times greater than that of atom transfer.

The completion of a double mass spectrometer system in 1966 permits the study of ion-neutral reactions over a range of interaction energies from below 1 eV up to 60 eV. The reaction $O^+ + N_2 \rightarrow NO^+ + N$ has been studied using this apparatus. The reaction cross section increases, with increasing kinetic energy of the O^+ ion, reaching a maximum of 8×10^{-16}cm^2 at 10 eV, and decreases at higher kinetic energies. These results are in good agreement with those obtained using other techniques.



The quadrupole mass spectrometer developed by AFCRL has proved to be one of the most valuable instruments available for measuring atmospheric constituents fom rockets and satellites. This particular spectrometer was designed for use in satellites.



COMPUTER SOLUTION OF REACTION RATES: Several hundred different reactions involving scores of different gaseous species take place in the upper atmosphere. Reaction rates are governed by many factors—temperature, incident solar radiations, mean free paths, concentrations of various species and so on. During the period, AFCRL scientists developed a computer program which solves reaction rate equations for 175 different reactions that can possibly take place among 18 different atmospheric species. The computer technique solves any size set of non-linear differential equations describing the transient behavior of individual atmospheric species, coupled with a set of exponential equations describing their equilibrium behavior.

The computer code has been used to compute the diurnal variation of the height profile of atmospheric constituents, including positive and negative ions as well as neutral species for several different geographic locations. It has been used to compute the variation of the 18 species during the November 12, 1966 eclipse. It has also been used to determine the time history of the free electrons and other constituents after a nuclear explosion in the atmosphere. The code has proven to be a powerful tool not only for computing these theoretical profiles but also for determining the relative importance of the 175 reactions at ionospheric altitudes and for showing the effects of using various rate constants for those chemical reactions whose constants have not been measured to date.

In a separate mathematical study, the Laboratory developed a simplified model of the nighttime lower F region. It was found that good correlation could be obtained between the true F region and a model involving the conversion of O^+ ions into O^+_2 and NO^+ ions by reactions with the neutral atmosphere. The correlation was best for the first half of the night. Large discrepancies in the latter half implied that large non-diffusive-type motions exist. This supports some past ionospheric studies which have suggested such motions. A study of the decay of O^+_2 and NO^+ ions in the above model compared favorably with radiation (the atomic oxygen red line) emitted in the F region.

The effect of particular interest was radio wave absorption, another factor that could also be modeled under the computer program. The investigators found that, under high reflective conditions, when a three MHz signal is transmitted through the ionosphere (as in satellite transmissions to the ground) absorption increases from the non-reflective case to the reflective case from 15.5 to 19.4 db. If a ground-based radiometer at three MHz is used to reflect a signal from the ionosphere, the expected decrease of echo field strength is 7.8 db when the light flux is doubled due to albedo.

SATELLITE ATTITUDE SENSING SYSTEM: A Laboratory designed-and-fabricated satellite attitude control system was provided to the McDonnell Aircraft Company for installation in the Gemini 10 spacecraft launched in July 1966 and the Gemini 12 spacecraft launched in November 1966. The AFCRL system

Rita Sagalyn of AFCRL displays a device for detecting vehicle pitch and yaw flown aboard the Gemini 10 and 12. The experimental system was pressed into operational service on the Gemini 12 flight when the vehicle's power system failed.

proved to be more sensitive, more precise, and demonstrated a shorter response time than the operational inertial systems aboard the spacecraft. It was also lighter, simpler and required less power. During the Gemini 12 flight when the fuel cells malfunctioned, the experimental system was pressed into duty as an operational system because of its low power requirement relative to that of the operational system. Performance exceeded everyone's expectations and proved to be so outstanding that the AFCRL system was used to align the Gemini 12 vehicle in the proper position for retrofire. An AFCRL scientist, on hand at NASA's Houston Mission Control, provided NASA control personnel with attitude information during most of the Gemini 12 flight.

The attitude control system exploits the fact that space vehicles in orbit about the earth move through a continuous stream of charged particles. This flow of charged particles can be detected by sensors. Sensitivity of the detection system varies with the orientation of the sensors with respect to the direction of motion of the spacecraft. With this as a basis, it is possible to design a system that can sense and control the attitude —the pitch and the yaw—of the spacecraft.

Two sensor systems—one to detect pitch, the other to detect yaw—were carried aboard both the Gemini 10 and 12. Each sensor was located on a boom extending out about two feet from the spacecraft. The two booms were separated by about 90 degrees near the midsection of the Gemini capsule.

The AFCRL sensor was designed to detect only ions. Relative to the high, randomly oriented electron velocities, which are 200 times greater than the slower moving ions, the spacecraft is essentially stationary. The spacecraft, however, has a velocity eight times that of the random thermal velocity of ions. Thus spacecraft velocity and direction relative to the ion environment can be detected.

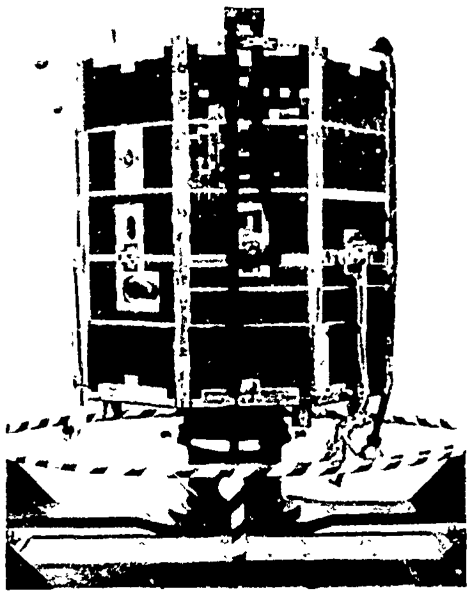
In measuring spacecraft attitude, the angular variation of a reference axis to a velocity vector is determined. If a conducting plate is placed perpendicular to the velocity vector of the spacecraft, and the flow of electrons is screened out, the flow of positive ions will produce a current to the plate. The current will decrease in an analytically predictable manner as the plate is rotated from the maximum current flow position which is perpendicular to the velocity vector.

Actually, a two-plate system is needed, with each plate being 45 degrees from a reference axis of the spacecraft. The flow of current from each should be equal when the reference axis is aligned to the velocity vector. When the reference axis is not aligned, the current flow in each of the two plates will be different, and this difference can become a measure of one component of the spacecraft's attitude—either pitch or yaw. Two systems, similar in all respects, are used, one aligned about the spacecraft's yaw axis, the other about the pitch axis.

The system has potentially wide application, not only in spacecraft, but possibly as an attitude sensor for supersonic aircraft.

SATELLITE MEASUREMENTS OF CHARGED PARTICLES: The attitude control system described above is essentially a fallout from AFCRL's more general research on electrical phenomena in the upper atmosphere and near space. Highly precise probes for measuring temporal and spatial variations and irregularities were placed aboard five satellites during the reporting period.

Most of these probes were incorporated in multi-purpose Air Force and NASA satellites. One satellite, however,



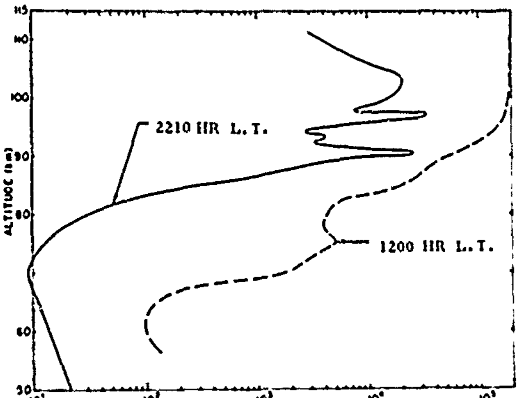
The OV3-2 was designed, fabricated and fully instrumented by AFCRL. Its primary mission was to measure irregularities in the distribution of electrons and ions.

the OV3-2, placed in a polar orbit on October 28, 1966, deserves special commentary. This satellite was designed, fabricated and fully instrumented by AFCRL personnel, with the overall engineering being the responsibility of AFCRL's Aerospace Instrumentation Laboratory (Chapter V). It carried an integrated payload for the simultaneous measurement of many related ionospheric parameters. The parameter of most interest was the irregularities in the distributions of electrons and ions. Upper Atmosphere Physics Laboratory experiments included two electrostatic analyzers to measure the fore and aft asymmetry in the angular distribution of trapped electrons, two orthogonally mounted retarding potential analyzers for the measurement of hyperthermal electrons and their angular distribution, an ion mass spectrometer to measure the positive ion composition, two spherical plasma probes to measure positive ion density, electron density and temperature, and the non-thermal distribution of electrons in the ionosphere and a standing wave impedance probe to measure small-scale irregularities in the electron density distribution.

The experiments thus were designed for coordinated measurements of irregularities in the ionosphere and, in particular, irregularities in the auroral zone. Concurrent with satellite observations of the aurora, the Laboratory's KC-135 ionospheric aircraft, which contains optical as well as propagation equipment, flew several missions into the auroral zone beneath the satellite and made simultaneous measurements.

The OV3-2 was still active at the end of the reporting period, providing large quantities of high-quality data. Another satellite in the OV3 series, OV3-1, launched in April of 1966, was also active and is providing data. The data from these satellites will not only give more precise information on diurnal and seasonal variations in charged particle distributions, but will also hold clues to other upper atmosphere processes, including heat transfer.

AFCRL instrumentation was also carried aboard NASA's OGO-B, launched in June 1966, to measure ion and electron flux and energy distributions throughout the magnetosphere and the variations in these quantities with time, position and level of solar activity. Improved charged particle sensing systems have been designed for placement aboard two more NASA Geophysical Observatories (OGO-E and OGO-G) and the NASA-sponsored Injun V, all scheduled for future launch. AFCRL has proposed that charged particle measurements be made on Apollo flights and is designing appropriate instrumentation for these flights.



At night, in the absence of solar energy, the number of free electrons in the ionosphere decreases markedly as the electrons set free during the day by chemical and collisional processes recombine with positive ions.

Measurement of electron and ion densities as a function of time and space is essentially a statistical process. It is difficult to separate spatial variations in the quantities measured from temporal variations when one looks at the data from a single rocket or satellite. Only after data are accumulated from many rocket and satellite experiments is it possible, by statistical means, to distinguish between space and time variations.

To get around this difficulty—at least in part—a synchronous satellite, the OV2-3, was instrumented in 1965. This satellite was intended to remain over one point on the earth (in the equatorial plane) and to monitor purely temporal variations which would have special significance at a 37,000 km altitude during solar disturbances. A launch attempt was made in December 1965, but due to failure of the launch vehicle (Titan IIIC), the satellite did not achieve orbit. A second vehicle has been instrumented and will be launched in November 1967.

ELECTRON REFLECTION: A classic effect in experimental physics is that of disturbing the environment with the probe used to measure it—thus invalidating the experimental result. Data from instruments sent into the upper atmosphere and space are particularly affected by free electrons. This problem led AFCRL to undertake a study to determine just what fraction of the electrons that strike a surface will stick and what fraction will bounce off again.

This study led to a technique for determining low-energy reflection characteristics of metal surfaces. It has already been used to show that only 15 percent of the low-energy electrons striking a special steel collector surface are absorbed while 85 percent are reflected under normal operating conditions. The method involves the trochoidal motion of electrons under the action of perpendicular electric and magnetic fields.

For impact energies less than a few volts, experiments indicate that the electrons that bounce off a surface do not lose much energy in the process. Such elastic scattering of electrons by a surface is called reflection, and the probability that an electron striking a surface will be reflected is called the reflection coefficient, R. The probability that this electron will be absorbed and contribute to the collected current is the (1-R). R is known to depend strongly on both the impact energy and on the characteristics of the surface itself. For a given metal surface and impact energy, the fraction of the incident electrons that stick and contribute to the collected current may vary from 95 percent to less than 20 percent, depending on the kind and degree of surface contamination. Absorption of even a monolayer of gas on a surface can cause large changes both in the magnitude of R and in the way that it varies with incident energy. As a result of this extreme sensitivity to surface charac-

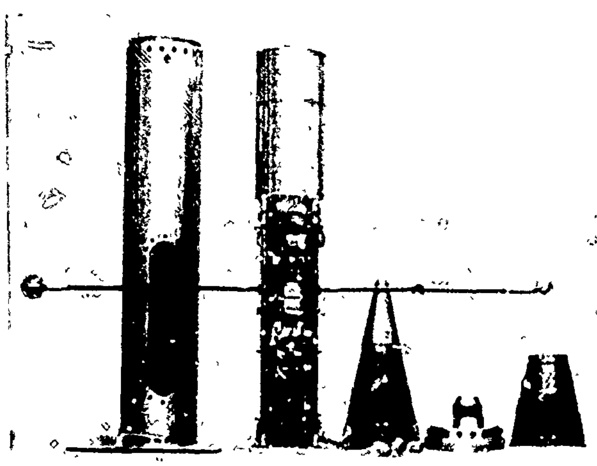
teristics, experimental measurements of R as a function of incident energy seldom agree with each other or with the predictions of the available theories. The reflection of low energy electrons by surfaces is, in short, a very poorly understood and unpredictable phenomenon.

ULTRAVIOLET RADIATION

The energy required to initiate and sustain the dynamic processes of the upper atmosphere is supplied almost entirely by extreme ultraviolet and soft x-ray radiation (or XUV) from the sun. For nearly a decade, AFCRL scientists have been in the forefront of rocket instrumentation to observe the nature and effects of solar ultraviolet radiation above the earth's protective atmospheric blanket. Because each atom, ion and molecule absorbs ultraviolet radiation at different wavelengths, these direct observations not only provide absolute intensity measurements of the solar XUV spectrum, but also an extremely valuable means of deriving information on atmospheric composition as a function of altitude.

AFCRL research on ultraviolet radiation has two parts. The first part involves rocket and satellite observations of solar ultraviolet absorption by atmospheric constituents at various altitude regimes and the direct observations of the sun's emissions of ultraviolet energy. During the past two years under this program AFCRL launched 11 rocket probes and two satellites equipped with XUV spectrometers.

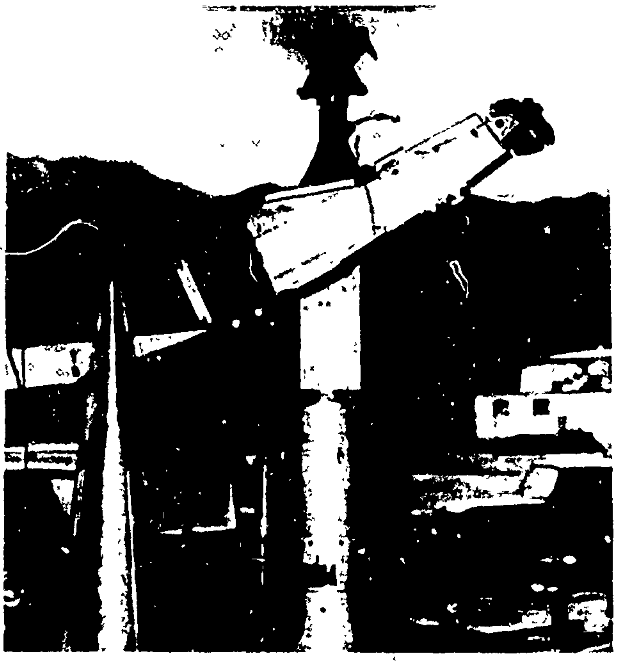
The second part involves ultraviolet spectrographic studies within the Laboratory where ultraviolet interaction with atmospheric atoms, ions and molecules can be studied under controlled conditions. Only in the laboratory can a particular atom or molecule be isolated for study. Here, large high-resolution spectrographic equipment can be used to resolve faint spectral absorption or emission lines of a given intensity.



A typical rocket payload for measuring properties of the ionospheric D and E layers is shown here. At the ends of the two long extended booms are charged particle sensors, one for electrons, the other for positive ions.

AFCRL operates some of the finest spectrographic equipment in the world for conducting such studies. This equipment consists of an one meter, a three meter and a 6.6 meter normal incidence spectrograph, a one and a two meter monochromator, and a 6.8 meter grazing incidence spectrograph. The 6.6 meter normal incidence vacuum spectrograph operates in the region between 300 and 12,000 angstroms.

ROCKET OBSERVATIONS OF XUV: Each of the 11 rocket payloads, launched between July 1965 and March 1967 to measure XUV radiation, carried a grazing-incidence grating monochromator (spectrometer) as the primary experiment. Depending on the choice of diffraction grating and detector for a given



Since the mid-1950's AFCRL has made solar ultraviolet measurements from rockets using a biaxial pointing control to keep the instrument located on the sun.

rocket flight, measurements were made either in the wavelength range of 30 to 130 or 230 to 1260 angstroms. The monochromators were designed either as scanners, in which successive scans of the entire spectrum are made only a few times during flight, or as fixed-wavelength, in which selected strong intensity lines are observed repeatedly, thus providing greater altitude resolution.

Although each successive experiment incorporated some modifications, the greatest single advance during this period was the replacement of the conventional photoelectric detector with a flow Geiger counter for the detection of short wavelength radiation down to about 30 angstroms, and the development of techniques for the laboratory calibration of this instrument. Retarding potential analyzers, which measure ion and electron densities, or gas-filled proportional counters for the measurement of soft x-rays (4 to 12 angstroms) were usually flown as auxiliary experiments.

All of the rocket flights, six from White Sands Missile Range and five from Wallops Island, provided usable data from 100 to 250 km altitudes, and were made during "quiet sun" conditions. Data acquisition during the entire flight trajectory is made possible by the use of a servomechanism known as a biaxial solar pointing control which points the sensor in the nose of the rocket accurately at the sun.

Some of the general results:

1) Intensities of solar XUV radiation do not appear to vary by more than a factor of 2 throughout the solar cycle. The photon flux ratios of selected spectral lines of the "quiet sun" were observed to be increasing during 1966, as the ascending phase of the 11-year solar cycle was entered.

2) Comparison of the atmospheric attenuation of solar extreme ultraviolet radiation on successive days showed that the composition of the atmosphere around 200 km does not change by more than 25 percent from one day to the next.

3) By means of a monochromator flown in November 1965, the absolute intensities of over 100 spectral lines in the range of 30 to 130 angstroms were determined.

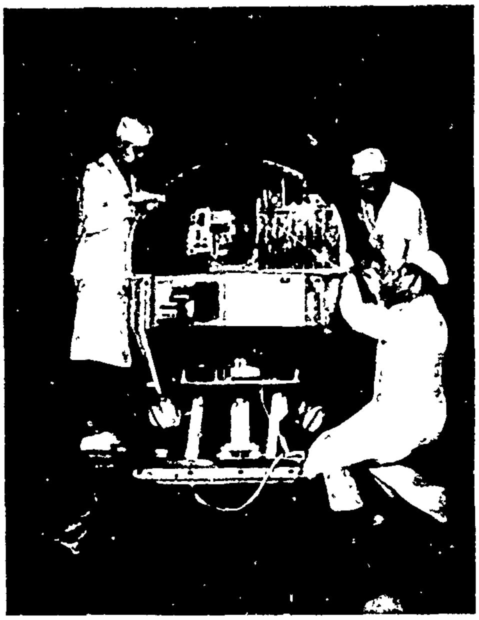
SATELLITE INSTRUMENTS FOR XUV: The Laboratory developed XUV spectrometers for both the NASA Orbiting Solar Observatory and the Orbiting Geophysical Observatory satellite series. Both of these spacecraft are solar oriented, although the accuracy of solar pointing is much better in the OSO series. Also, the OSO's are placed in

equatorial orbits, while the OGO satellites have polar orbits.

OSO-III was launched on March 8, 1967, and has been eminently successful. The AFCRL instrument, a grazing-incidence grating monochromator, monitors solar radiation fluxes in the 250 to 1300 angstrom range, and can be commanded to scan the entire range or to observe any chosen wavelength continuously. In addition to measuring the ionizing fluxes of solar radiation incident upon the earth's atmosphere as the primary objective of the experiment, various secondary objectives such as absorption characteristics of the upper atmosphere, including density and composition studies, and short-term temporal intensity variations, are being realized.

Another spectrometer was developed for the polar-orbiting OGO series. OGO-II was launched on October 14, 1965, but since the spacecraft was not oriented toward the sun, only a small amount of data was acquired during the first few days of operation. The next launch, OGO-D, is scheduled for the latter half of 1967. An improved version of this spectrometer is being developed for OGO-F, which will be launched in 1968. All of these instruments will scan the spectral range of 170 to 1700 angstroms in six overlapping bands, and can be commanded from the ground to operate on selected short scans within this range.

SPECTROSCOPIC PROGRAM SURVEY: When a molecule of one of the constituents of the upper atmosphere absorbs a photon of solar radiation, one of a number of possible processes may occur depending upon the energy possessed by the photon. The molecule may be raised to some higher electronic and/or vibrational state, following which it may lose some or all of that absorbed energy through radiation or through collisions with other molecules, ions or atoms. It



AFCRL UV spectrometers were carried aboard several NASA satellites of the OGO and OSO series. The AFCRL spectrometer is seen extending from the bank of solar cells.

Dr. Y. Tanaka examines the assembly of the three meter grazing incidence vacuum spectrograph.

may be dissociated into one of several possible combinations of products consisting of atoms which may be neutral, ionized, excited or some combination of these. It may be singly ionized, or it may be ionized with the ion excited to some higher electronic energy state.

These basic processes can be observed in detail and with great accuracy using precision laboratory instrumentation. Laboratory studies are designed to provide answers to questions such as: What is the probability that any specific molecule will absorb a photon of specific energy? What effect on the molecule does such absorption have? What energy must a photon possess or a collisional process possess in order to dissociate a molecule when it is in a specific energy state? What energies are required to ionize or to doubly or triply ionize a specific molecule? What are the possible photon energies with which a specific molecule can radiate absorbed energy, and what is the probability that it will radiate a photon of specific energy? What is the length of time that a molecule will remain in some specific energy configuration before it does radiate?

These studies involve optical spectroscopy, primarily in the vacuum ultraviolet spectral region at wavelengths shorter than 2000 angstroms. Emission and absorption spectra of the gases of interest are obtained under a variety of conditions of electrical excitation, pressure, and temperature. Study of the many electronic band systems which occur in the emission and absorption spectra of such molecules leads to knowledge of the electronic energy structure of the molecules. Likewise, an accurate determination of absorption and ionization cross sections also contributes to the knowledge of expected results of the interaction between the molecules of interest and electromagnetic radiation.

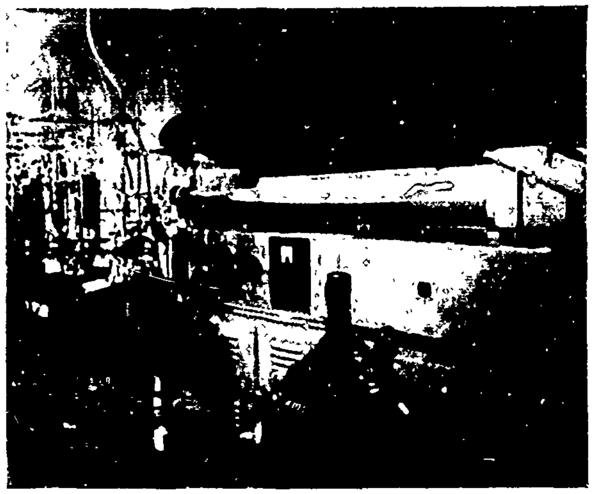
Other investigations include studies of lifetimes of metastable states; studies of mechanisms responsible for various afterglows; studies of fluorescence induced by UV radiation; studies of selective excitation; studies of pre-dissociation and pre-ionization phenomena, and studies of perturbations among electronic states or vibrational energy levels. Such investigations provide the knowledge that is essential to the formulation of a theoretical framework. And only through such a framework can the observed processes of the upper atmosphere be explained.

SPECTROSCOPIC STUDIES: Atomic oxygen is an important constituent in the D and E regions of the ionosphere. But little is known experimentally of the absorption cross section for this atom in the spectral region below 2000 angstroms because of the difficulty in handling this specie in laboratory experiments. Laboratory studies of the absorption spectrum of atomic oxygen have yielded over 170 energy levels previously unobserved for this atom. An experiment is also underway to detect atomic oxygen in the upper atmosphere with rocket-borne instrumentation in the altitude region 80 to 120 km using the technique of absorption spectroscopy.

A phenomenon which may be of significance in upper atmospheric processes is that of "associative ionization" initiated by vacuum ultraviolet radiation. Studies show that ionized argon molecules occur when argon is irradiated with vacuum ultraviolet radiation even though the radiation does not possess energy equivalent to or in excess of the ionization potential of the argon atom. It is surmised that the ionized molecules are formed through collisions between neutral and excited atoms of argon.

Nitrogen dioxide is considered the most important "air" emitter at temperatures below 1000 degrees K. During the period, Laboratory scientists obtained more complete data on emission spectra from thermally excited nitrogen dioxide in the 1000 degrees K temperature region. There seems to be some indication that the process responsible for the thermal emission in nitrogen dioxide is related to the process responsible for the emission resulting from the interaction between nitric oxide and atomic oxygen to form nitrogen dioxide.

An experimental technique developed by the Laboratory and known as "selective excitation" has been used to obtain considerable new knowledge of the electronic energy structure of molecular hydrogen, deuterium and HD. The selective excitation results from an electrical discharge through a mixture of the gas of interest, such as hydrogen, and a rare gas such as argon. Collisions between electronically excited argon and the hydrogen result in energy transfer followed by selective emission by the hydrogen.



The Laboratory uses six spectrographs of various sizes for UV studies. The glassware at the left of the photo is used to prepare various gas mixtures for spectrographic analysis.

AURORA AND AIRGLOW

The faint luminescence in the earth's atmosphere that is known as airglow, and the more brilliant—sometimes spectacular—luminescence of the aurora are produced primarily by photochemical reactions and particle impact. Airglow is mostly due to photochemical reactions, the aurora to particle bombardment. But the line of demarcation between the two is not well defined and both phenomena, in their optical manifestations, at least, are usually considered together. Both originate principally in the altitude region between 80 and 100 km, where most of the recombination of atoms that gives rise to the luminescence occurs. An exception, however, is 6300 angstroms radiation which occurs in a slightly higher altitude. They show very definite differences at different geographical points and at different times of the day, year and sunspot cycle.

From the standpoint of delicate optical surveillance devices, both airglow and the aurora represent so much "noise" which degrades sensor data. It is this underlying fact that motivates AFCRL's research in this field. Measurements have been carried out by ground-based instrumentation, aircraft, and rockets. The results of these measurements for the past two years are briefly discussed below. (Additional research on the aurora and airglow is conducted by AFCRL's Optical Physics Laboratory, Chapter X.)

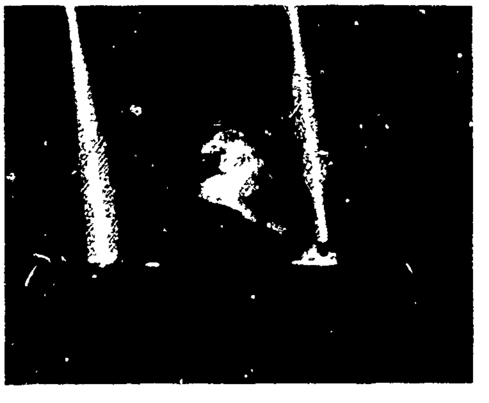
SACRAMENTO PEAK MEASUREMENTS: Ground-based measurements of the major airglow emissions were carried out

at AFCRL's Sacramento Peak Observatory in New Mexico (see Chapter III) during most of an 11-year sunspot cycle. This unique body of data provides a basis for a full analysis of the general behavior of airglow emissions and their correlation with solar parameters.

Several prior studies had demonstrated correlations between both mean annual and mean monthly intensities of the 5577 angstrom (OI) line of the night airglow and corresponding mean solar activity, expressed in terms of sunspot area or sunspot number. The green line intensity measurements obtained at the Sacramento Peak Observatory (32 degrees 43′ N; 105 degrees 45′ W) from November 1956 to June 1963 were analyzed for correlation with two indices of solar activity, Zurich relative sunspot numbers and 10.7 cm solar flux. The analysis was performed on both a mean monthly and mean nightly basis and was further subdivided (arbitrarily) in terms of solar cycle phase. It was found that a statistically significant positive correlation exists between monthly and nightly averages of green line activity and both Zurich relative sunspot numbers and 10.7 cm solar flux. The 10.7 cm flux, however, showed a somewhat higher correlation with green line activity than is shown by Zurich relative sunspot number. It was found that the degree of correlation is dependent on the phase of the solar cycle.

The 6300 angstrom (OI) airglow emission was also observed at Sacramento Peak. A monotonic decrease in 6300 angstrom emissions was observed to occur during the night, typical of temperate latitude stations, on days when there was little or no magnetic disturbance. On magnetically disturbed nights emissions were variable. Maximum variation occurred during the night, usually to the south, which appears to be a northern extension of the

Associated with aurora are geomagnetic activities which disrupt communications and degrade radar detection capabilities. One AFCRL aurora experiment called for the simultaneous launch of two rockets, an Aerobee and an Astrobee. These two rockets were launched from Ft. Churchill, Canada.



equatorial behavior. The increased intensity of the 5577 angstrom (OI) airglow emission following a magnetic storm commencement (previously noted by others) was confirmed using data from Sacramento Peak, Mexico, and Huancayo, Peru. The time of the maximum intensity following the SSC (Sudden Storm Commencement) of the order of one hour and the amount of the

increase of the order of 5 percent are comparable to those previously noted. The AFCRL data, however, indicate that the effect begins prior to the SSC.

The Sacramento Peak data were also used for a statistical study of the mid-latitude aurora from 1955–1963. As expected, auroral activity showed very strong correlation with sunspot cycle. During sunspot maximum, for example, a K_p (magnetic storm index) of 4 usually indicated auroral behavior while during 1961, K_p could reach 6 with no indications of auroral behavior. Another study of aurora showed that auroral heights in the antarctic, which had not previously been measured, were the same as those in the Northern Hemisphere.

More recently, the airglow continuum in the immediate vicinity of the strong line emissions of the airglow was measured at AFCRL (Bedford, Massachusetts) by introducing a second rotating polarizer in a birefringent filter photometer. The results were compared with those obtained by other workers using different techniques. It was shown that the method would be useful for the study of the continuum in the immediate vicinity of the airglow. Additional analyses of airglow instrumentation were carried out. In particular, an important distinction in the calibration of a birefringent photometer between line and continuum was pointed out. An analytical description of a Fabry-Perot photoelectric spectrometer useful in the analyses of these data was made.

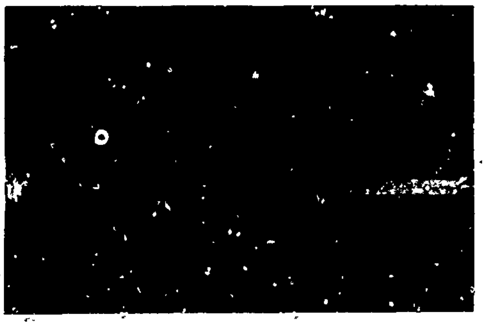
ATMOSPHERIC TEMPERATURES FROM AIRGLOW EMISSIONS: The three parameters which define the state of the atmosphere are composition, density, and temperature. In principle, the knowledge of any two of these parameters will fix the value of the third. Since at this time there is no satisfactory way to describe the atmosphere by an equation, the independent measurement of all three parameters is necessary. Because of the low pressures encountered in the upper atmosphere, the temperature measurements become relatively complex, to the extent that temperatures are usually derived from density measurements. A promising technique for temperature measurements of the upper atmosphere is by optical means, where the kinetic velocity of emitting particles is measured by means of their Doppler widths in the case of atoms, or from band profiles in the case of molecular species. Radiating species can be introduced by chemical release by rockets, but this method is limited to a few locations where there are established rocket launch facilities. The use of the naturally occurring radiative species of the upper atmosphere provides an easily available means to measure temperatures from ground sites at any designated location.

Because of the small effect caused by Doppler broadening, high-resolution spectroscopic techniques are necessary. These emissions are inherently very feeble and large luminosity instrumentation is required. Fabry-Perot interferometers are quite well suited for this type of task and have been used to carry out these measurements as part of synoptic study of nightglow temperatures. The radiations chosen for study were the red and green oxygen lines of the night sky since their approximate height of emission is well known. The advantage of this type of measurement is the ability to make continuous ground measurements of the temperatures at high altitudes. Rockets, by contrast, provide only short time measurements and are costly. Measurements of temperatures by these means have been carried out

under a continuous monitoring program since early 1965.

SKY BRIGHTNESS DURING ECLIPSE: The sky during an eclipse takes on a deep violet hue, and the shadows in the landscape darken to a sombre coloration. Is the coloration real, or is the deepening quality of the light nothing more than that seen daily at twilight, or when clouds obscure the sun? Is the effect a result of the sudden transition from a bright sky and therefore explained in terms of dark adaptation and color perception by the human eye?

The zenith skylight intensity was measured with a resolution of ten angstroms over the wavelength range from 5200 to 6400 angstroms during a total solar eclipse on July 20, 1963 at Hermon, Maine, and the November 19, 1966 eclipse at Bage, Brazil. When comparisons were made of the intensity distributions of wavelengths at totality and in the zenith sky at twilight, it was found that the shorter wavelengths are more intense during the eclipse than at twilight. For example, at 5400 angstroms, the value of the zenith intensity is about 18 kilorayleighs during an eclipse compared with about 14 at twilight. But at 6000 angstroms, the intensity values are roughly the same—about four kilorayleighs. The study concludes that there is a shifting in intensities toward the blue during an eclipse.



This photo of a total eclipse was taken from AFCRL's KC-135 from an altitude of about six miles as the aircraft followed the path of eclipse totality.

ROCKET PROBES OF AURORAS: The physics of auroral activity is indistinctly understood—but what is understood has been established largely by rocket probes directly into auroras. These probes have detected the precipitation of both protons and electrons into the auroral zone. It has been established that electrons, however, supply the energy for the auroral light. It has also been pretty well established, theoretically at least, that the precipitated particles do not come directly from the sun and are not the result of particle dumping from the radiation belts. The latter conclusion is based on the fact that the energy required to sustain auroras is so great that the radiation belts would quickly be depleted of particles, and this depletion has not been observed. Most researchers believe that the particles originate in the solar wind and penetrate the earth's magnetic field on the dark side of the earth along the indistinct and elongated tail of the magnetic field where lines of force are weak. The particles then work their way back toward the earth. What then happens is one of the subjects of current investigation.

During the period, AFCRL launched five rockets into visible auroras to measure the energy distribution of the incoming primary auroral particles and the height profile of the electron and ion densities and temperatures.

Two NIRO rockets were launched in October 1965 at Fairbanks, Alaska, in a coordinated program sponsored by the Defense Atomic Support Agency. Simultaneous measurements were made with an auroral radar located at Homer, Alaska, ground-based optical facilities

at Fairbanks and from aircraft and a satellite. In spite of the fact that the operation had to be conducted under very austere field and support conditions where no established launch site existed, AFCRL was able to launch the two rockets into Class I and II type auroras.

In another program, the two rockets launched into visible auroras at Churchill, Canada, on December 12, 1966 were fired 30 seconds apart, and each rocket contained many complementary experiments to make the most complete measurement to date of the relationship between primary auroral particles, light emission, and low energy electrons.

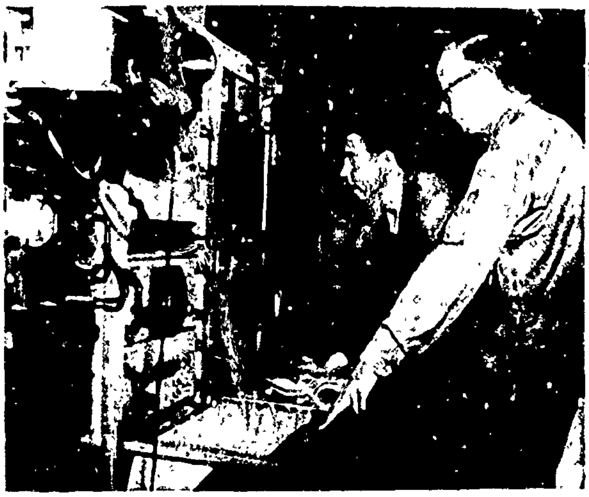
These investigations have shown that the structure, behavior, and mechanism of an active aurora cannot be easily derived from a knowledge of the primary electron spectrum arriving from the magnetosphere. The flux of secondary electrons which is responsible for the production of thermal electrons shows a much finer structure than the primary electron flux of several keV energy. The reason must be sought in an instability which produces currents and electric fields inside an aurora. A simple detector of the retarding potential type which measures the total electron flux above 75 eV is a useful instrument for determination of the electron production rate by energetic electrons. Recombination coefficients derived from these data are consistent with those obtained by other measurements. Electron temperatures were lower than predicted by theory.

The fifth rocket, a Black Brant, will be launched from Ft. Churchill in 1967 to study a polar cap absorption event. The polar cap phenomenon, which increases in frequency with the 11-year active solar cycle, causes communications blackout in the polar region due to the onset of severe ionization of the D region of the ionosphere. Polar cap absorption is believed to be caused by solar flares of a particular type. The primary instrument on board was a proton detector with an energy range from three to 100 MeV. Other instrumentation included a magnetometer, positive ion detector, retarding potential analyzer, x-ray, Langmuir probe, impedance probe, radiometer, conductivity probe, Lyman-Alpha detector, scintillator, and cylindrical retarding potential analyzer.

THE IONOSPHERE

Previously considered were the chemical processes and the energy mechanisms that create and sustain the ionosphere. Here the gross features of the ionosphere itself will be considered, with special emphasis on radio techniques used to probe the ionosphere and the effects of the ionosphere on radio signals.

A unique facility for ionospheric studies is AFCRL's ionospheric flying laboratory. During the period, the KC-135 aircraft was modified to incorporate a number of new equipments. (Another AFCRL KC-135, used for optical physics research, was also reinstrumented in this period.) Chief among the new equipments was a Granger ionospheric sounder, the first aircraft installation of such equipment. Other equipments include photometers, visible and infrared spectrometers, gamma ray monitors, and a variety of processing and recording equipment. The aircraft participated in two eclipse expeditions (to the Mediterranean in May 1966 and to South America in November 1966) to measure the effects on the ionosphere during the brief interval when the moon obscures the sun. The largest single KC-135 program, however, consisted of a series of flights to the Southern Hemisphere in March and April of 1966—flights which



Among the special equipments in AFCRL's ionospheric research aircraft is this Granger ionosonde. Other equipments are photometers, spectrometers, gamma ray monitors, and a variety of processing and recording equipments.

twice took the aircraft across the coastline of Antarctica.

The Air Force has a direct interest in two aspects of ionospheric research. First, the ionosphere influences Air Force communication and detection systems. Second, the ionosphere may provide clues to the detection of missile launches, based on the fact that missiles passing through the ionosphere set in motion ionospheric waves that may be detected over great distances. The ionosphere is a delicate, unstable layer that is easily disturbed. The first three studies covered in this section relate to such disturbances.

MISSILE-INDUCED IONOSPHERIC DISTURBANCES: A missile passing through the fragile mantle of the ionosphere can create ionospheric wave motions that radiate out over great distances. This wave motion is induced by the missile's exhaust. In the extremely low pressures of the upper atmosphere, the exhaust balloons outward several diameters larger than the missile itself. This fact is pointed out to show that the streamlined missile penetrating the ionosphere does not produce the ionospheric wave; it is produced by the velocity of the outwardly expanding gas.

The disturbances can be detected by radio reflection techniques. As the traveling ionospheric wave passes over an observer there is a change in electron density. The magnitude of the change is proportional to the intensity of the wave. The wave motion is detected by changes in phase of the reflected signal caused by the disturbance. Because the ionospheric height from which a radio wave reflects varies in a well known way with the frequency transmitted, it is possible for the experimenter to select the altitudes at which the ionospheric disturbance is to be measured.

To study missile-induced ionospheric disturbances, AFCRL established several sites along the Atlantic Missile Range. By observing missiles launched from Cape Kennedy, the Laboratory hopes to learn more of the altitude, distance and time dependence of the ionospheric disturbances. Radio reflection and optical techniques are used to study missile exhaust characteristics as a function of the ionospheric shock waves they produce. The geographical configuration of the sites permitted measurement of the exhaust structure size as a function of angle of illumination.

From the observations of ionospheric disturbances, it is possible to characterize many features of the missile which created the wavethrust and size, for example. Based on observations of Cape Kennedy launches, and the study of controlled ionospheric perturbations produced by AFCRL rockets, the Laboratory validated and refined a theory by

which it is possible to derive missile parameters from the characteristics of the induced shock wave.

TRAVELING IONOSPHERIC DISTURBANCES: To explain atmospheric movements one can study the theory of wave motion in ideal fluids and relate the results to phenomena observed in the atmosphere. The theoretical concepts involve the description of acoustic gravity waves in model thermospheres as well as the study of internal gravity waves in relationship to ionospheric phenomena.

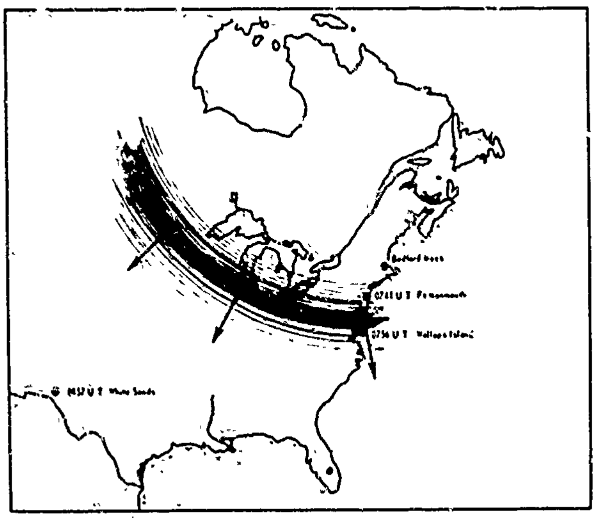
It has been observed that F region Traveling Ionospheric Disturbances (TIDs) support the gravity-wave interpretation since they display a wave-like characteristic. Their observed periods fall in the predicted range, and the observed velocities agree with theory. These traveling disturbances are produced by a variety of phenomena such as auroral precipitation events, earthquakes, nuclear blasts, missiles, and high flying aircraft and by processes such as weather systems, convection, nonlinear tidal interactions, winds blowing over mountains, jet streams causing instabilities and so on.

Depending on their periods, TIDs propagate in the atmosphere with speeds ranging from about 300–1000 meters per second. They are sometimes observed to travel over long distances in which case they usually display a large frontal extent. The disturbances which originate in the auroral zone are produced by precipitating energetic particles with energies less than 100 keV. Their energy is probably converted into an atmospheric wave in the height range between 100 and 150 km. The resulting waves travel toward the equator.

Aurorally produced nighttime disturbances have been observed at AFCRL (Bedford, Massachusetts) using oblique HF radio transmissions. They have a period of about one hour, a wavelength of about 1200 km and travel with a speed of about 340 meters per second toward the south. The F region was lowered from 260 to 230 km in 30 minutes while its critical frequency increased by 10 percent. Although the details of the interaction between the ions and the neutral gas are not well understood, the electrons which control the behavior of phase and group path for HF radio waves are assumed to be driven by the pressure wave in the neutral gas.

When this missile reaches the ionosphere, it will set off a train of waves in the fragile ionosphere which will propagate outward for hundreds of miles. These waves can be detected by radiometric equipment.

Using data from an ionospheric sounding network, the extent of the disturbance was determined. In a typical case, the deep trough of a wave extending in



The aurora can set off a traveling disturbance in the ionosphere which propagates southward as a wave front thousands of miles long.

a giant arc from Ft. Monmouth, New Jersey, in the east, through Chicago and into Winnepeg, Manitoba, in the west, was observed at 0741 U.T. By 0857 U.T. the depressed point had swept southwest past the tip of Florida in the east to White Sands, New Mexico, in the west.

EFFECTS OF MAGNETOSPHERIC MOTIONS: The magnetosphere—the space containing the geomagnetic field and the plasma of the upper atmosphere—has a highly asymmetric shape because of the compression by the solar plasma wind on the dayside. Co-rotation of a large part of the magnetospheric plasma with the earth and simultaneous compression by the plasma wind produce an alternating ascending and descending motion during the course of a day. The plasma arrives at minimum altitude around noon and at maximum altitude around midnight. The primary motion, normal to the force lines and accompanied by an electric field, can be interpreted as the motion in a modified Alfvén wave (hydromagnetic wave) of standing wave character. The amplitude of the vertical velocity component at ionospheric heights is estimated at roughly 20 meters per second (in low latitudes).

The alternating compression and expansion of the magnetospheric plasma will have various effects in the lower magnetosphere or ionosphere. The oscillatory magnetic field in the modified Alfvén waves appears as a variation of the geomagnetic field, which behaves similarly to the magnetic field variation observed on the ground. It remains, however, to be investigated to which degree this hydromagnetic variation of the geomagnetic field continues down to the ground.

At heights between F2 maximum and roughly 2000 km the rapid decrease of the plasma density and neutral gas density with height cause a strong coupling between modified Alfvén waves and ion-acoustic waves. The compression and expansion of the magnetosphere during a day, representing a standing modified Alfvén wave, leads consequently to the generation of ion-acoustic waves of a 24-hour period. In the ion-acoustic waves a plasma motion along the force lines and a considerable variation of the plasma density are encountered. The progressive compression in the modified Alfvén wave, taking place at low latitudes in the forenoon, moves plasma down to lower heights. The ion-acoustic wave supplies plasma to this area, sucking it in along force lines. The result is a reduction of the plasma density along the force lines, which is maximum around the time of maximum compression of the magnetosphere. This process might explain the depressed electron concentration in the F2 layer at low latitudes in the middle of the day.

Similar processes to those expected on unperturbed days occur during magnetic disturbances when the magnetosphere is temporarily in a state of stronger compression.

RIOMETER NETWORK: The riometer (relative ionospheric opacity meter) is an instrument used to measure changes in ionospheric absorption of radio energy. AFCRL operates a riometer network composed of 13 stations at various locations all over the world. This network provides long term data for a synoptic study of ionospheric absorption. Data for a complete year for each station are required for constructing a "quiet day" curve for each site. Departures from this standardized "quiet day" curve are analyzed in relation to observations of other environmental phenomena in an effort to derive cause-and-effect relationships.

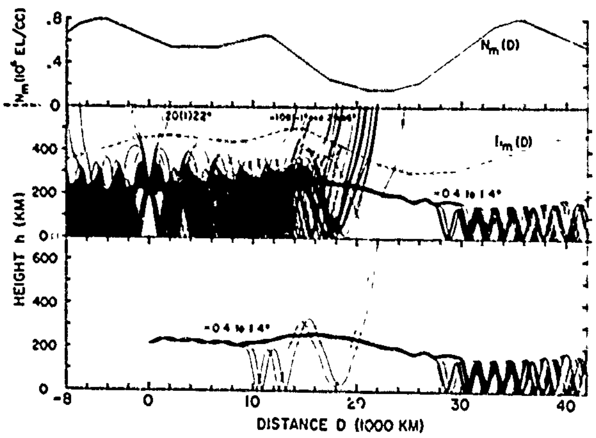
D REGION SOUNDING: As an outgrowth of the experimental work in radio probing of the lower ionosphere using VLF and LF transmissions, two important requirements have become apparent. First, pulse transmissions are necessary to determine the region of reflection so that group height variations are obtained as well as phase height. Secondly, the use of multiple frequency transmissions will allow the D region to be probed simultaneously at various heights.

To meet these two requirements, a new sounding system has been proposed. This system will transmit narrow pulses at frequencies in the range 25 kHz to 500 kHz. The sounder will provide a complete description of the ionospherically reflected pulses in digital form and will be recorded on magnetic tape for direct input to the AFCRL computer. This system will add a new dimension to radio pulse probing studies of the lower ionosphere by providing a description of D region behavior in height as well as in time.

The mathematics of the system were established from observations of solar eclipse induced phenomena. The solutions of a set of lumped parameter electron-ion rate equations are plotted as a function of time during a solar eclipse. Both x-rays and Lyman-Alpha solar fluxes, the radiations which produce the D region ionization, are slowly eclipsed by the moon for the 60 minutes after first contact followed by one minute of totality and then by a symmetrical recovery phase for 60 minutes. Cosmic ray production is assumed constant during the eclipse.

In general there are two regions of distinct behavior in the lower ionosphere. Below 75 km where attachment and detachment processes dominate, the electron density follows the variation of the eclipsed flux with no apparent delay because of the speed of these processes. Between 100 and 85 km there is a delay in the time of minimum electron density after totality. This delay varies from less than one minute at 100 km to almost ten minutes at 90 km. The dominant processes in this region are dissociative recombination and ion pair production. As the production becomes smaller at lower altitudes, the magnitude of the eclipse effect becomes smaller while the delay becomes large. In the transition region, 80 to 85 km, both processes are important, and a complicated behavior is to be expected.

RAY TRACING STUDY: What kind of path will a radio signal of a given frequency take during transit between transmitter and receiver? This depends on many things—latitude, longitude, and altitude of transmitter, direction of propagation, time of day, season, and



When a satellite at 200 km transmits a radio signal, the rays of the signal take many paths. These paths are plotted in the upper panel. Those rays which are trapped in a duct in the ionosphere are depicted separately in the lower panel. They sometimes travel completely around the world before escaping.

solar conditions. Varying electron density is the primary determinant of the path taken by a radio signal. There is, of course, not just a single path taken by a signal between transmitter and receiver, but a continuum of rays within an angular interval of the antenna beamwidth which contributes to the signal.

The ionospheric and magnetospheric index of refraction varies with three space coordinates and, due to the presence of the geomagnetic field, also with the direction of propagation. Because the refractive index distribution is inhomogeneous, the ray paths followed by radio signal energy emanating from a transmitter are complicated and often form unusual ray patterns. These patterns can be obtained by solving a set of simultaneous differential equations. AFCRL uses computers of both the analog and digital types for research in ray tracing.

Ray tracing research conducted by the Laboratory involves observation, calculations and machine computations leading to ray path prediction, and observations again to verify predictions.

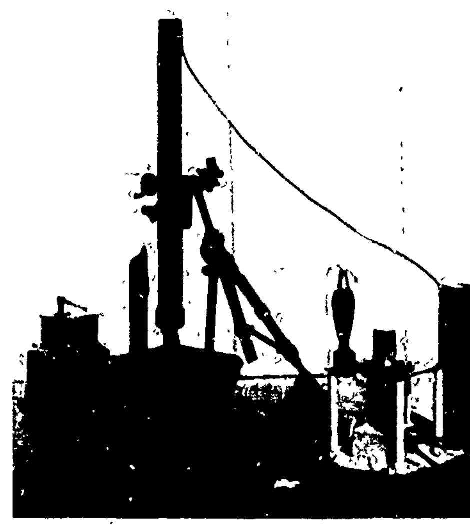
Observations are made by AFCRL along several propagation paths. During the reporting period, oblique-incidence propagation paths were operated between Uruguay and Puerto Rico, and between Puerto Rico and Bedford, Mass. These paths were used to study the propagation of radio signals at 160 discrete frequencies within the band from four to 64 MHz, with Granger-type ionospheric propagation sounders which rapidly scan the 160 frequencies every ten minutes, for 24 hours each day. The data are being correlated by ray-tracing calculations based on electron-density data.

LF/VLF PROPAGATION

Low Frequency (30–300 kHz) and Very Low Frequency (3–30 kHz) radio signals propagate to great distances in the "waveguide" formed by the surface of the earth and the lower ionosphere. In the VLF region, the waves are remarkably stable and predictable in both amplitude and phase. For this reason they are particularly well suited for long range communications under normal and disturbed ionospheric conditions, long range navigation, long range detection and location of natural and man-made radiation sources, and timing systems.

To achieve reasonable radiation efficiencies at these long wavelengths, the traditional antennas are very large fixed structures. The development of more compact structures, and of more convenient deployment techniques poses some interesting challenges. Up to the present time, practically all VLF cir-

cuits have made use of transverse magnetic modes in the earth-ionospheric waveguide because these modes produce large fields near the earth's surface. Theoretically, transverse electric modes must also exist, and these may have important future applications. One potential capability is that of communicating directly from a satellite above the ionosphere to a submarine submerged in the ocean, since it is known that long radio waves can penetrate sea water to a considerable depth and, at least under some conditions, can also penetrate the ionization of the upper atmosphere. At the present time, exploration of ionospheric penetration phenomena has barely begun.



To simulate EM pulses induced by lightning strokes, AFCRL sent aloft a thin steel wire attached to a mortar shell. The wire plays off on a spool and when extended serves as a radiating antenna to transmit VLF pulses.

LF/VLF SIGNAL CHARACTERISTICS: These studies are concerned with latitude, altitude and diurnal effects on LF and VLF signals. Facilities for conducting these studies consisted of AFCRL's network of receiving stations in the New England area, mobile receivers, and Exos rockets.

With the New England network of receiving stations, signals from a distant transmitter were simultaneously compared at the three sites of the network. The phase differences between the signals received at the sites should remain constant if the propagation conditions varied uniformly on different propagation paths. Measurements, however, showed the existence of a repeatable (and hence, predictable) diurnal variation, upon which was superimposed an apparently random fluctuation. Studies of these fluctuations have shown that it is possible for a network of receiving stations to find the geographic location of an unknown transmitter with great accuracy, an order of magnitude greater than that previously possible with conventional direction finders.

Other studies using mobile receivers synchronized by Loran C permitted the effect of changing geometric configurations to be observed. It is curious that the phase correlation for some transmitters is much greater than for others, and in one case the propagation stability —at least under normal daytime conditions—was greater than could be measured although the equipment could resolve a change of .2 microsecond.

The accuracy of radio location, ionosounding, and time transmission depends on having a sufficient signal to noise ratio, or a suitably low probability of natural noise contamination. For the case of certain pulse signals, the theoretical connection between noise amplitude distribution and signal phase error has been established, and supporting measurements have been made.

Two Exos rocket probes launched from Vandenberg AFB carried VLF receivers from the ground to 500 km altitudes to measure the variations of signal amplitude, polarization, and phase and group delays as a function of altitude. Signals from distant (several thousand kilometers) VLF transmitters were received at all altitudes. Some of the results are consistent with a simple propagation model in which the geomagnetic field plays a dominant role. Other features require sophisticated mathematical treatment for their interpretation. More rocket flights are planned for different geomagnetic latitudes.

SFERICS RESEARCH: AFCRL has conducted research on sferics (lightning discharges) for well over a decade. A network of sferics detection sites, established under this program and operated over a period of six years, was dismantled in the spring of 1967. The worldwide geographic distribution of sferics, however, is still being studied. Studies have concentrated on the exceptionally large sferics which occur only a few times per year per 100 square miles. The amplitudes, initial polarity, and other features of these "giant sferics" have been investigated.

The possibility of triggering natural lightning by rapidly lofting a thin steel wire into the air by means of a cannon shell has been repeatedly demonstrated. The wire plays off from a spool which remains attached to an instrumented terminal connected to ground via a low resistance shunt. The free end of the wire is sent up when the clouds overhead reach a suitable level of electrification as indicated by field strength measuring instruments. The ability to have lightning strike a designated terminal makes possible electrical, magnetic, photographic and other studies which would otherwise be impossible. After the main current of the discharge dies out, the trail of ionized plasma in the air still lingers, thus opening interesting possibilities for future electromagnetic experiments.

Another study involving the suspension of long wires was one originally undertaken to simulate sferics-induced EM pulses. AFCRL pioneered in the technique of radiating high power (30 megawatt peak) pulses from a 25,000 meter antenna wire supported vertically by a helicopter. The antenna was shock excited by the discharge of a million-volt condenser bank. Such signals have been used primarily for experimental purposes. For future tests, attention is turning to the possibility of using long wire antennas for radiating at extremely high altitudes, using balloons and satellites as transporting vehicles.

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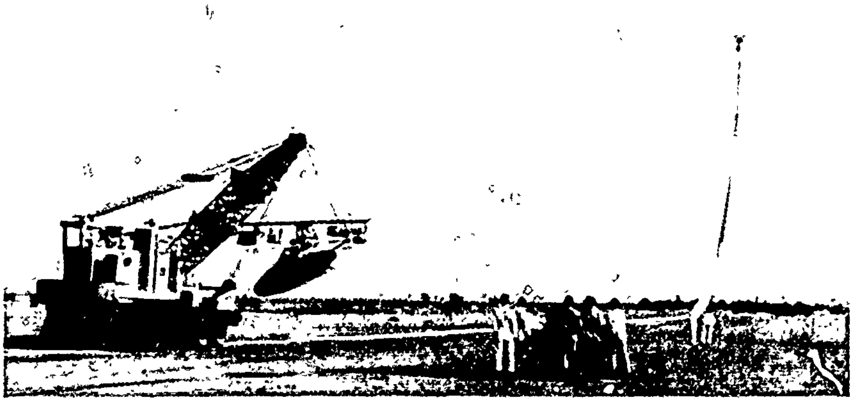


Under NASA's Voyager program for soft landing a package on Mars, AFCRL developed the largest balloon ever fabricated — twice the size of any previous balloon. In these photographs, only the upper balloon of the two-balloon Voyager system is inflated. The much larger lower balloon is inflated by the expansion of gases from the upper balloon.

V Aerospace Instrumentation Laboratory

Sounding rockets, satellites and balloons—the probe vehicles—are the data gatherers of aerospace research. Leading to the launch of each vehicle is a preparation effort measured in months or years—vehicle procurement, payload integration, establishment of tracking and telemetering networks and range safety planning. The work of the Aerospace Instrumentation Laboratory involves all of these preconditions, as well as launch responsibility itself. After the launch, the Laboratory collects the data and arranges for its decommutation. The work is carried out for other AFCRL laboratories (primarily the Upper Atmosphere Physics Laboratory, Optical Physics Laboratory and the Space Physics Laboratory). A sizable part of the Laboratory's workload supports other DoD and government laboratories.

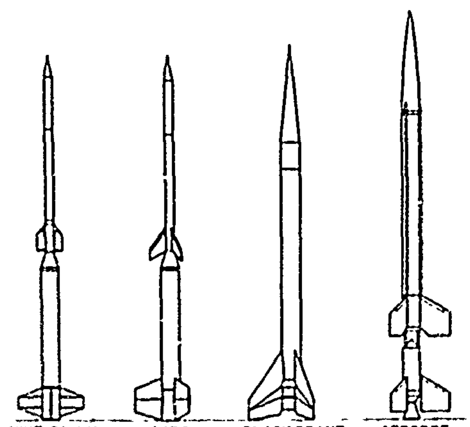
With respect to rockets and satellites, the Laboratory not only provides design and fabrication of specific experimental payloads, but is responsible for obtaining the best boosters for the flight profiles. Part of this responsibility is development work that might lead to the upgrading of rocket performance in general. During the period of this report, the Laboratory had the responsibility for the launch of 104 rocket probes, with a 90 percent success rate, and the management of the launch of six satellites, four completely instrumented by AFCRL.

The Laboratory during this period launched more large plastic research balloons than any other agency in the country, and probably in the world.

From its two balloon launch sites at Holloman AFB, New Mexico, and Chico, California, it launched more than 300 of these large balloons. Some remained aloft for days or weeks—but the usual balloon flight is measured in several hours.

A major grouping of Laboratory activities is in the field of design climatology. Design climatology considers the special demands of the environment in which rockets, aircraft, balloons, and satellites operate. The design of vehicles of optimum efficiency—and often the validity of resultant experimental data —depends on precise knowledge of the winds, temperatures and densities through which a vehicle passes. Further, the planning of many Air Force operations is based on the probability that certain climatological conditions will be met at some future time. The design climatologists can provide these probabilities.

A third Laboratory program is the development, engineering and testing of meteorological equipment for the Air Force inventory—and, in fact, this effort carries AFCRL further into the development end of the R&D spectrum than any other AFCRL effort. Based on requirements set forth by the Air Weather Service and the national missile ranges, the meteorological equipment group undertakes the development of operational equipment.



During the reporting period, AFCRL launched 12 Nike-Cajun rockets, 29 Niro rockets, 2 Black Brants and 26 Aerobees.

ROCKET AND SATELLITE PROGRAMS

AFCRL has instrumented and launched more rocket probes than any single research laboratory in the world, and has placed scores of instrumented packages aboard satellites—both those of NASA and the Air Force. The program has grown from a few experiments on the early V2 rockets to multiple experiments on a diversity of rockets and satellites.

During the two years' activity covered in this report, AFCRL launched 104 large sounding rockets (see Appendix C). Four completely AFCRL-instrumented satellites were launched. The Laboratory participation ranged from complete design, fabrication, instrumentation and testing to supervision of installation of experiments on contractor-produced satellites.

The Aerospace Instrumentation Laboratory manages the AFCRL probe research program. Management of the program has many facets including vehicle selection, range scheduling, structural design, payload integration and fabrication and systems for data transmission and decoding. Laboratory personnel plan with each scientist the overall data flow from basic sensor to final report.

Most of the 104 rockets launched during the reporting period were launched from three primary ranges—Eglin AFB, Florida, White Sands Missile

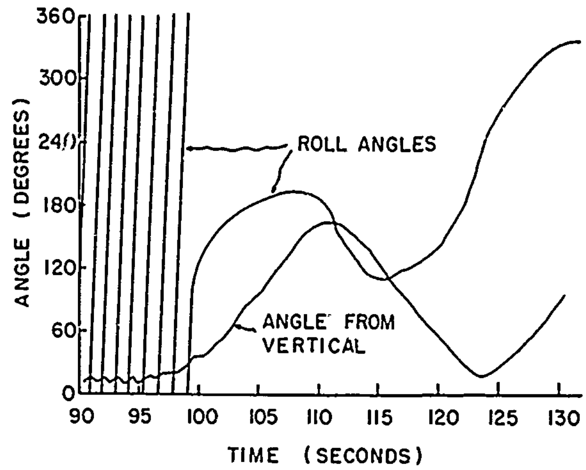
Range, New Mexico, and the Ft. Churchill Range in Canada. But launches were also made from Puerto Rico, Sweden, Alaska, and Brazil.

ROCKET FLIGHT DYNAMICS: Ideally, a rocket would maintain absolute stability from the time of launch through apogee and downward descent. Except where otherwise programmed, there would be no rolling moments, no oscillation about the longitudinal axis, no variations in angle of attack and, of course, no vibration. If all of these could be precisely controlled, there would be no ambiguity in data interpretation, and larger amounts of useful data could be collected on each rocket flight.

The physics of the problem is such that instabilities will probably never be completely eliminated, but through the work of aerodynamicists in this Laboratory and others concerned with rocket design, problems have become increasingly tractable. More and better data are obtained from each rocket flight, and major systems failures have steadily declined.

Two typical design problems may be briefly stated. The first of these is that of downwash turbulences of the nose cone and the resultant effect on fins. These fin interference effects are now well enough known so that proper angles of fin incidence can be established prior to flight to allow the accurate preplanning of the vehicle roll rate as a function of time.

A second problem has been that of predicting at all times during flight the angular orientation and spatial position of payloads in flight. Such knowledge is usually necessary for data analysis. If the knowledge of rocket spatial position is precise, instrumentation can be designed in such a way as to take spatial position into account and instabilities can be discounted.

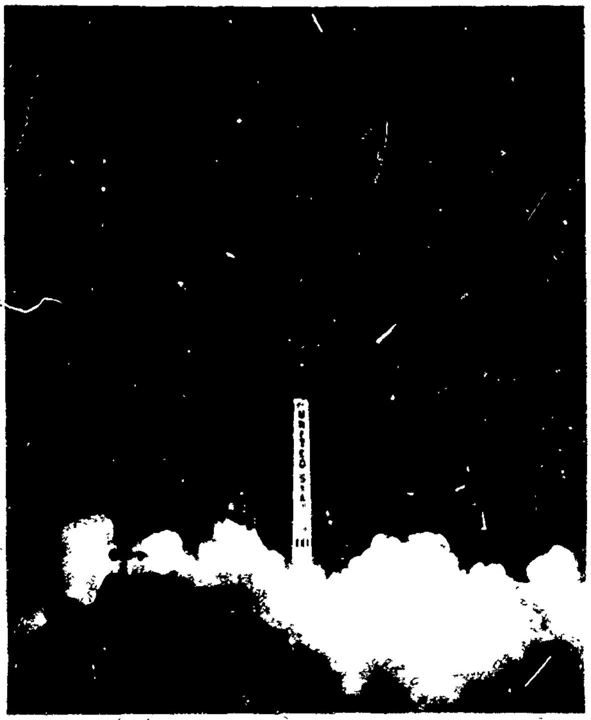


The above plot deals with rocket stability. The traces show that at 99 seconds (380,000 feet) the rocket suddenly and violently undergoes a change from a well-behaved resonant roll with a low angle of attack to a very low rate with large angle from the vertical. The cause is not fully understood.

The most radical changes in the ideal motion of the vehicle occur at a time in flight when external forces are small—that is, in the rarefied upper atmosphere. These violent changes are characterized by a sudden decrease in roll rate about the longitudinal axis, a very large increase in angle of attack, and assumption of an approximately pure coning motion with one side of the body always facing the axis of the cone. Some investigators postulate that the Magnus force (that same force that puts the curve on a baseball) is the dominant upsetting cause, but Laboratory investigations lean toward the possibility of a forebody wake with fin interaction. Although the analysis is not complete, it has been determined that the induced rolling moment versus angle of attack curve is best approximated by a cubic equation and that the simple linear assumptions of the

past are invalid. The solution of this interesting and complex problem will yield knowledge of local aerodynamic effects useful in better understanding of the whole regime of sounding rocket flights.

It is through analysis of this kind that reliability and predictability are brought into the sounding rocket program. The wide variety of experiments conducted and the expressed plans of the experimenters indicate that the era of the sounding rocket extends at least to the five year limit of our planning horizon and most probably beyond that. Studies of the sort indicated above are required to raise the level of expertise from that based upon engineering judgment and experience to well based forecasts of design adequacy. With proper design, fewer flights are required to make a reliable measurement, and fewer resources are expended.



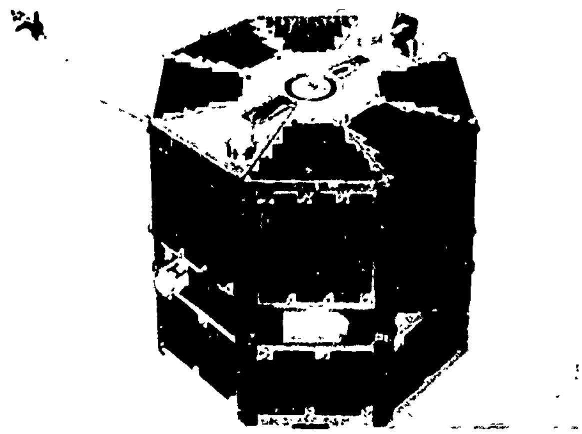
The four-stage Scout rocket was used by AFCRL to place six OV3 satellites in orbit. AFCRL manages the OV3 satellite program for the Air Force.

OV SATELLITE SERIES: The OV satellite series consists of some 30 to 35 low cost satellites under the management of the Office of Aerospace Research, AFCRL's parent agency. The first successful launch under the series occurred in October 1965. Since then some 20 additional OV satellites have been launched. It is anticipated that in the period subsequent to June 1967, an additional ten to 15 will be launched. OAR has in turn redelegated a sizable portion of its management responsibilities to AFCRL. AFCRL works intimately with the Space Systems Division and the Ballistic Systems Division on various OV satellite programs. Payloads come from a diversity of laboratories—various Air Force laboratories, Air Force contractors, university experimenters, and of course from AFCRL.

Of the satellites in the program, the Aerospace Instrumentation Laboratory has the most direct responsibilities for the OV3 satellites. Six were scheduled in the initial program. Of these, two were totally designed, fabricated, integrated and tested within the Laboratory with all scientific sensors being provided by AFCRL experimenters. The four remaining spacecraft, two instrumented by AFCRL and two by other Air Force activities, resulted from contractual endeavor. Close technical supervision of all contractor and experimenter efforts was assumed by engineers of the Aerospace Instrumentation Laboratory.

Of five OV3 launches in a span of less than ten months during 1966 and 1967, one failure resulted from a vehicle malfunction. The four successful satellites at the conclusion of this report (June

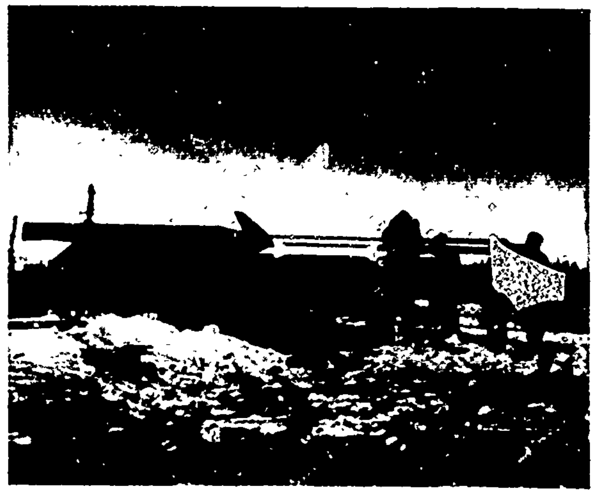
1967) continue to provide useful scientific data. Conversion of the enormous amounts of data to a form useful to the experimenter is a formidable task undertaken by the Laboratory. The data are first converted to an analogue form for early analysis and determination of experiment and satellite health, and then to a digital tape for final analysis by a computer. The Laboratory then turns these data over to the experimenter.



The OV3-5 satellite was instrumented by AFCRL to measure atmospheric composition and to obtain data on charged particles in the near space region.

INSTRUMENTATION FOR LAUNCHINGS AT REMOTE SITES: Most rockets are launched from established launch sites because of the range support needed for tracking and for receiving telemetered information from the rocket. This places a severe limitation on the scientist who often must obtain environmental data at specified geographical latitudes where there are no established launch sites. This limitation has led AFCRL to develop instrumentation and tracking systems to support launchings from temporary launch sites. During the present report period, launchings were conducted from temporary sites in Alaska in connection with ground auroral studies and at Puerto Rico in conjunction with measurements made by the Arecibo Radio Observatory.

In general the rocket-borne electronics is kept simple forcing greater complexity on the ground instrumentation. However, trade-offs can be made, and with proper design of the rocket-borne electronics it is possible to launch rockets from remote sites where the usual range support is not available. In such cases a minimum of conventional ground receiving equipment is necessary. AFCRL has tested two such probe systems on NIRO rockets. One of the systems provides tracking as well as telemetry information in the same unit, thereby reducing the number of components and the



For certain rocket experiments, data are required at locations other than established rocket launch sites. Here, AFCRL is preparing a NIRO rocket for launch at a temporary site in Wainwright, Alaska.

additional weight and drag of multiple antennas. This system requires the modification of a standard airborne transmitter by addition of an ultra stable reference oscillator. The ground receiving part of this system is somewhat more complicated and is capable of tracking the received frequency to a high degree of accuracy. An ultra stable reference oscillator, similar to the airborne unit, is included in the receiver circuitry, enabling a Doppler frequency component to be extracted from the received signal which is used to compute slant range.

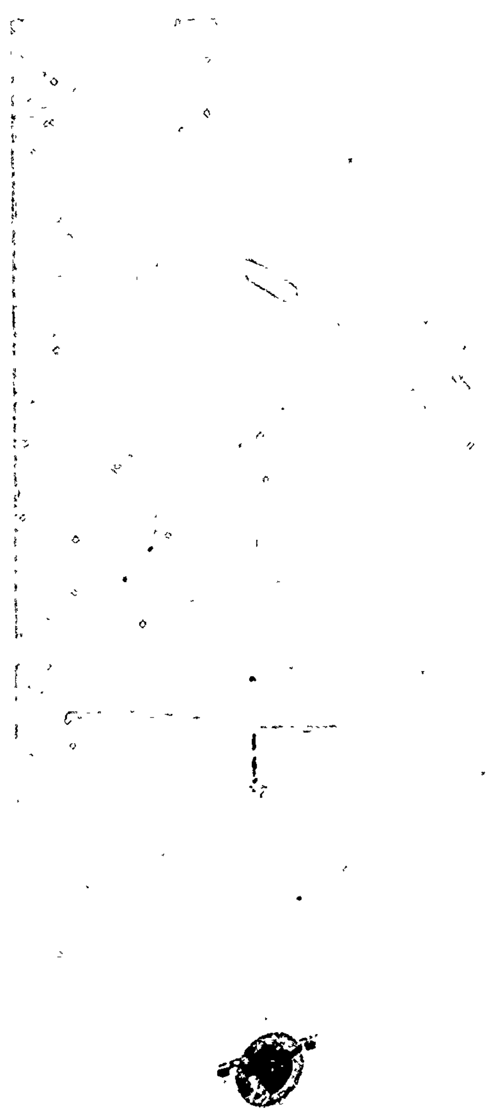
The second system tested is an inexpensive solid state oscillator which is capable of being frequency modulated. This unit provides the tracking signal for a portable meteorological tracker, the GMD-2, which gives azimuth, elevation, and ranging information.

Additional flexibility has been added to the program by the development of a water recovery system for the NIRO rocket. The system, usable either on land or in water, allows experiments to be conducted which require physical recovery from any area of the earth's surface where rocket launchings are possible.

BALLOON TECHNOLOGY

The Laboratory is the largest developer and user of balloons in the United States—and has been for the past decade. Each week, AFCRL balloon launch crews send an average of three large balloons aloft. These balloons carry payloads, sometimes measured in tons, to altitudes of from 70 thousand to 130 thousand feet.

The Laboratory has the primary responsibility for Air Force balloon research and development, a responsibility



The entire Voyager system at the time of launch extends 815 feet in length. The balloon will reach an altitude of about 131,000 feet.

that extends to all aspects of balloon system engineering. The Laboratory provides counsel and flight support for AFCRL, numerous universities, and many government agencies. An increasing number of applications are being found for large balloons in high altitude research and in military applications, an increase reflected in the growth of AFCRL's balloon program.

During the past two years, both altitude and payload capabilities were increased. The high altitude payload capability was greatly extended when two balloons (26 million cubic feet in volume) were flown in support of the NASA Voyager program. The largest balloon previously flown (in January 1965, also by AFCRL) had a volume of 13.5 million cubic feet. With respect to increased payloads, a 10,300 pound instrumented payload was carried to an altitude of 70,000 feet. Both missions presented unusually difficult technical problems and both were highly successful on their very first flights.

During this reporting period, the Laboratory initiated an extensive tethered balloon program. Tethered systems are under study for use in communications relay systems, and, in particular, for communications in theaters of operation such as Vietnam. A capability now exists to tether from a fixed location to an altitude of 10,000 feet. Various studies are in progress, both in-house and under contract, for establishing compatible balloon tether-cable configurations and operational procedures toward a goal of a 60,000 foot tethering system.

More than half of the 150 balloon flights in 1966 were launched from AFCRL's balloon launch facility at Holloman Air Force Base, New Mexico. An additional 30 percent were launched from AFCRL's other launch site at Chico, California. The remainder were launched from remote locations.

This rare photo of the fully inflated Voyager balloon was taken from a camera in the Voyager capsule as it was propelled upward by rockets after release. The small blister atop the balloon is the smaller launch balloon shown in the previous photo.

The Laboratory has continued its sponsorship of balloon symposia on an annual basis. These symposia provide a comprehensive coverage of balloon technology and have been attended by hundreds of engineers and scientists representing scores of organizations.

FREE BALLOON DEVELOPMENT: The goal of AFCRL's balloon development program is to produce more reliable balloons for carrying heavier payloads to higher altitudes. During the reporting period there has been a measurable increase in the reliability of polyethylene balloons, a direct consequence of the use of films extruded from new polyethylene resins. These balloons, carrying payloads up to one ton, have had a success factor exceeding 90 percent. There has also been an increasing requirement for heavier payload flights for which the unreinforced polyethylene balloon is not

Preparations for balloon launch usually begin in the early morning hours. Shown here is the Voyager system capsule plus balloon instrumentation arranged along the payload bar.

suitable. Families of reinforced films, principally Mylar film and Dacron fibers in various thicknesses and deniers, have been developed to provide balloons of nearly 100 per cent reliability for heavier and usually more expensive payloads. The AFCRL Flying Thread Loom, discussed in the previous *Report on Research*, made the fabrication of these improved materials possible.

PROJECT VOYAGER: In 1966, AFCRL launched two balloons each measuring 26 million cubic feet in volume, twice the volume of any previously launched balloon. Designed by AFCRL for the NASA Project Voyager (and funded by NASA), the balloon performed perfectly in meeting the requirements of placing a one-ton capsule over a specified target at an altitude of 130,000 feet—an unprecedented payload-altitude combination. Two flights of the Voyager balloon took place, the first on July 18, 1966, and the second on August 30, 1966.

The experiment, involving rocket acceleration of the capsule, provided a full scale evaluation of a parachute system to be used in the soft landing of the Voyager instrumentation on Mars, planned for the 1970's.

At the time of launch the balloon extended to a vertical length of more than 815 feet (Washington Monument: 555 feet). Its inflated diameter at altitude was 410 feet. The balloon alone cost somewhat more than $100,000. The use of previously available reinforced materials would have involved a balloon with a volume of approximately 54 million cubic feet if the same payload were taken to the same altitude. It would have cost about $235,000.

TETHERED BALLOONING: Interest in tethered ballooning has burgeoned in recent years. Tethered systems reaching altitudes of 60,000 feet now appear feasible, largely because of advances in cable technology. The stable elevated platform capable of remaining on-station for extended periods, which these balloons represent, is of interest both to the experimenter and to the military field commander.

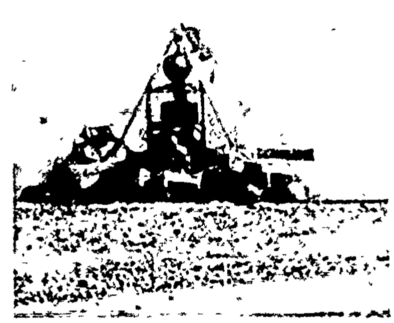
Investigation of tethered ballooning technology for high altitude operation began in late 1965. A specific operational requirement called for tethering a 50-pound (later a 300 pound) payload at an altitude of 10,000 feet for 12 or more hours. A cursory, and then a detailed, study of the weather indicated that a spherical balloon tethered to a steel cable could perform adequately in wind speeds up to 20 knots. Simplicity in operation was paramount. As devel-

oped, the system consists of a hydraulically operated winch, an oblate balloon (which becomes spherical at an altitude of 10,000 feet) high strength steel cable, and safety control instrumentation.

During this developmental program, several related efforts, initiated earlier, began to show promise. A hydraulic winch for high altitude tethering was designed and ordered, and a computer program was formulated for solving the problem of tethered system design involving variables of wind, cable, balloon payload, safety factors, and so on. Initial computer runs indicated that the spherical tethered balloon system can perform satisfactorily at altitudes up to 20,000 feet, at wind speeds up to 20 knots (if Fiberglas tethering cable is used) and at altitudes up to 15,000 feet when steel cable is employed. An additional effort was made to develop aerodynamically shaped Fiberglas cable to minimize wind drag on a high altitude balloon system. Initial tests in progress as of June 1967 to determine the optimum means of deploying the cable were encouraging. However, cable performance in the real atmosphere has not yet been tested.

The Surveyor lunar landing vehicle was tested for NASA by AFCRL by releasing the package from a balloon. After release, rockets slowed the descent of the vehicle.

BALLOON DROP TESTS OF SURVEYOR: In another program involving tethered balloons—one without the complexity of high-altitude tethering—the AFCRL balloon group assisted NASA in testing the soft-landing capabilities of the Surveyor lunar vehicle.



More than 70 tethered balloon ascensions to an altitude of 1500 feet for vehicle drop tests were conducted at Holloman AFB, New Mexico, to test the Surveyor spacecraft's retrofire descent and impact capabilities. The balloon in effect provides a stable drop tower without the impediments of a tower structure itself. The tethered balloons used

in the tests were 66 feet in diameter. To achieve the stable platform and to allow the Surveyor vehicle to be dropped free of any possible entanglement with tethering lines, three winch-equipped trucks were employed. The tether lines formed a triangle. The Surveyor test vehicle was suspended beneath an open parachute. After drop, vernier rockets fired at 800 feet, and cut out at 500 feet. From that height, the parachute recovery system brought the vehicle to the ground with an impact approximating that of the lunar landing.

BALLOON INSTRUMENTATION: One reason for the increased use of balloons in research and for certain military operations is improved balloon instrumentation. An instrumented balloon system usually carries tracking beacons, pressure gauges, data acquisition devices, telemetry, and radio receivers and relays used to control balloon altitude by ballasting or gas valving.

Instruments developed in recent years not only give more reliable and efficient performance, but simplicity of construction and packaging have greatly reduced costs and the manpower needed to assemble and mount the various instrument components. AFCRL took the initiative in packaging standard instruments in modular units, each compatible with the overall system and easily replaced in case of malfunction. As progressive changes and modifications in these units come along, the new units are readily adaptable to the overall system.

Apart from basic instrumentation, one new development is the use of a UHF-FM data link system carried within the balloon system (the balloon plus the payload) itself. The purpose of this device is to eliminate wire conductors which add weight and complexity. Many experiments call for the payload to be configured beneath the balloon in a long train. These various experiments are turned on or off by means of coded HF signals from the ground-based command center. With the new internal UHF-FM data link system, the receiver in the main payload area picks up the command and relays it to the appropriate system by a low-power radio signal. The internal data link system, which weighs only a few pounds, has its greatest utility, however, with respect to the balloon's valving mechanism. The balloon valve is usually located at the top of the balloon, and in the past a conducting cable, often stretching 500 feet or more from the main payload package through the balloon to the top, was used to relay commands to the valving mechanism. This cable was a source of potential damage to the balloon material and added weight. The internal UHF-FM data link permits the transmission of valving commands without the need for the cable.

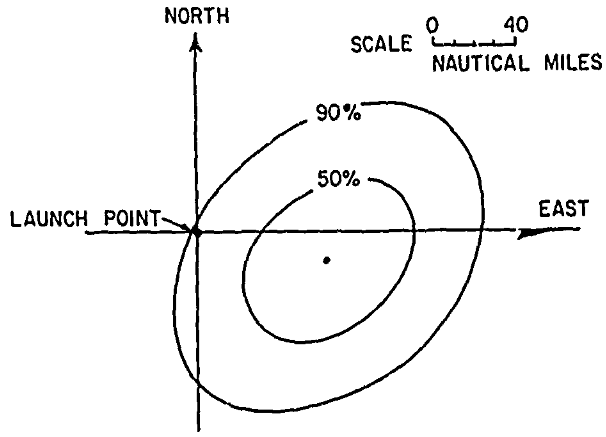
Many payloads, because they are militarily classified or because of the danger of environmental contamination of certain collected atmospheric species, must be recovered immediately. This means that pickup crews must be at the spot when the payload descends on its parachute. Because the trajectory of the balloon and the parachute which carries the payload to the ground after the termination of the flight are highly influenced by the winds, the pickup crews must be able to communicate frequently and reliably with the Balloon Control Center which is tracking the balloon. A simple balloon-borne transponder has been developed which provides more reliable communications. The transponder is carried aboard the balloon being tracked. Normally, the transponder is on the stand-by mode. When it receives a signal on one frequency, the main relay system is activated on a second fre-

quency. The balloon then becomes a high-altitude relay station, retransmitting messages between the control center and the recovery crews. This system can also be used in military theaters of operations for over the horizon communications—and in fact is under consideration for use in Vietnam.

All balloons carry a pressure altitude sensor. A standard sensor, the AFCRL-developed hypsometer, has been used for several years. The hypsometer senses altitude as a function of the boiling temperature of butyl benzine. At 145,000 feet, the boiling temperature and the instrument package temperature are of the same order, about 25 degrees C. The butyl benzine at the higher altitudes will boil off in a few hours without the application of heat. By introducing a bath of alcohol (which serves as a coolant because of its much lower boiling temperature) around the hypsometer, the instrument is now usable for flights to altitudes of 158,000 feet.

Above 158,000 feet, there is presently no instrument for measuring pressure accurately. A new approach is being considered based on the principle of heat transfer. Accuracies to 100 feet have been achieved in laboratory tests in the 100,000 to 200,000 foot altitude range. The device, which consists of thermistors, solid state control circuitry, and a small tube, is subject to drift but the drift can be limited to a daily error of about 100 feet by electrolytic deposition techniques on the tube. The cumulative error is acceptable for flights of several days at the higher altitudes.

FREE BALLOONS AND ENVIRONMENT: Not too long ago, operational predictions of just where the balloon payload would eventually come down had large conjectural overtones. During the past several years many refinements have come to the art of balloon trajectory control and prediction. The art largely consists of taking advantage of different wind regimes in the stratosphere which are catalogued by balloon operational analysis for each flight. Using this information, the skillful flight director, by either gas-valving or ballasting, can effect the slight altitude shifts which are often all that is needed to place the balloon in a more desirable wind stream.



Trajectory dispersion patterns (of the type shown above for a hypothetical balloon launched from Omaha in the winter months) are derived from climatological data. The dispersion probability plots tell the flight director where the balloon is likely to be when it reaches altitude.

Knowledge of the ascent trajectory is important for several reasons: air safety, positioning of recovery crews and ground support equipment, and the determination of the probable-line-of-sight above the horizon when the balloon is at float altitude. AFCRL has made a thoroughgoing analysis of the winds that affect balloons during ascent, and from this study has derived a method for making probabilistic estimates of just where the balloon will be when it reaches float altitude. By applying a formula to a series of charts, the balloon

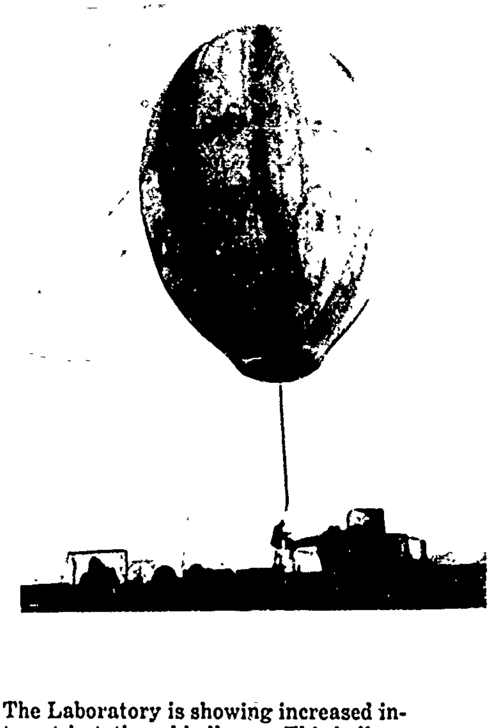
flight director can predict the probabilities that a balloon will be within a well defined area when it reaches altitude. These data were compiled for each season and cover balloons launched anywhere in the continental United States.

Such charts are only an adjunct to the requirement for more precise meteorological data at the time of launch. The launch is made only after the meteorologist has assured the flight director that a range of meteorological conditions are satisfactory—surface winds from balloon layout through launch time, cloud coverage at launch and enroute, humidity, temperature inversions and their height, strength and duration, wind speed, shears, tropopause height, wind vectors at float altitude, and many others. From the complex integration of these variables, the meteorologist predicts the touchdown point of the payload so that the recovery crews can be deployed.

Requirements often exist for keeping a balloon within a specified area throughout an entire flight. This technique is known as "station keeping." While, in general, the winds will carry a balloon away from its launch site, the proper selection of operating area, altitude, time of year and the control of altitude by valving gas and dropping ballast afford the possibility of hovering the balloon near its launch site or another specified location. This concept is best realized during the summertime at approximately 65,000 feet and has application in the use of balloons as communications relay platforms or as reconnaissance vehicles.

Still other requirements call for the precise positioning of a payload over a specified target at a specified time. Usually these flights are intended to use optical instrumentation on a range or to occur in conjunction with some other event which is limited to a specific time and place. For successful operation they require careful selection of launch site and a detailed examination of the meteorological conditions affecting ascent and float trajectories.

Analyses of the distributions of errors in time and distance for 150 of these precision balloon flights conducted by AFCRL at White Sands Missile Range show that 50 percent of the trajectories were within five miles of target center and within five minutes of the scheduled event time. Another 30 percent had miss distances of less than ten miles and time errors of less than 18 minutes.



The Laboratory is showing increased interest in tethered balloons. This balloon was designed to ascend to 20,000 feet on a tethered line. The design permits the balloon to expand during ascent to its float altitude without distortion of symmetry.

TETHERED BALLOONS AND ENVIRONMENT: Winds, thunderstorms and precipitation present special problems for tethered balloon operations. The most critical consideration is dynamic pressure, a function of atmospheric density and the square of the wind speed. This varies widely according to geographical locations, altitude and time of year. A comprehensive climatological analysis was prepared for use in the design phase and in the development of an operational plan for a tethered balloon system to be used in the southeastern United States. A unique feature of this analysis is the estimation of the expected durations of wind speeds in relation to design criteria and operational requirements. Additional studies of a similar nature are being made for other locations. What is sought is a set of statistical probabilities on the amount of time that a tethered balloon system will be operational, given a particular balloon design and operational altitude.

BALLOON SUPPORT: Omitted from this discussion are a multitude of programs supported by the balloon group. Some 25 different programs were supported during the reporting period and this number alone, because of space, precludes discussion in any detail. Many programs imposed unique design requirements which had to be engineered before the flights took place. For example, one experiment entailed a multi-element payload extending in a half-mile train from beneath the balloon, the total payload weight being 2500 pounds. Techniques for the deployment of this train of individual packages at altitude were ingeniously contrived, but it was nevertheless only one of many special-problem assignments.

DESIGN CLIMATOLOGY

In the previous section, under the discussion of tethered balloons, the feasibility of designing a balloon that can ascend to 60,000 feet on a tether was noted. But the question arises as to whether an operational system involving tethered balloons would be worthwhile in the first place if winds and atmospheric densities in a particular theater of operations are such that the system could be deployed only 15 or 20 percent of the time.

It is the role of the design climatologist to provide the system planners with such climatic data related to projected systems and operations. These data will

Climatology studies often involve the statistical analysis of historic meterological trends from which can be derived probability statements on future meteorological averages and extremes.

often strongly influence the system design. While the role of the design climatologist has been stated here in terms of only one type of vehicle—balloons—the role also extends to aircraft, to rockets, to satellites, and to ground equipments and facilities.

The design climatologist starts with the collecting of wind, temperature, humidity, pressure and other data which he averages by season, geographic location and altitude strata. Somewhat more difficult is the next role of providing probability distributions of atmospheric parameters. And more difficult still is the function of providing conditional limitations—that is, given a particular set of climatological data for one day, what will be the probability that certain critical values of these data will not be exceeded on the next.

Nevertheless, the foregoing concerns only the statistical manipulation of climatic records. Beyond this, the AFCRL group in design climatology is engaged in more general research. This research involves the very descriptions of atmospheric parameters. Is it possible to derive from statistical data a description that may have enhanced utility when considered in a particular operation, situation or as a vehicle design criterion? For example, one might ask whether the standard temperature profile can be reduced to a mathematical formulation which is more meaningful to a specific user. Further, the AFCRL group is considering better descriptions of the behavior of atmospheric parameters acting in concert.

Several programs of the AFCRL design climatology group during the reporting period are covered below, with the first in the series serving primarily as an example rather than achievement, because of its routine nature.

CAMROC RADOME: When the Cambridge Radio Observatory Committee (CAMROC), a committee set up by MIT, Lincoln Laboratory, Harvard and the Smithsonian Astrophysical Observatory, began in 1965 to investigate the feasibility of a large radio observatory in the Boston area, climate was a major initial consideration. Of special concern was a proposed 500-foot radome. The CAMROC group was interested in the climatic extremes—snowfall, rain, winds and wind gusts, extremes of cold and heat, hail and icing and so on—that the radome might be subjected to over its projected 25-year lifetime.

Ordinarily, the engineer of a large structure has the latitude to grossly overspecify in the interest of structural soundness. But the design of a radome poses a special problem because its mass must be kept at a minimum to avoid undue attenuation of radio waves passing through it.

AFCRL provided the CAMROC group with the stated climatic extremes that might be expected during a 25-year period, which the CAMROC group and their engineers could use in their attempt to obtain a minimum mass and a maximum structural soundness, and with a 99 percent expectancy of its lasting 25 years. Such data were provided for a range of locations within a two-hour driving range from Boston.

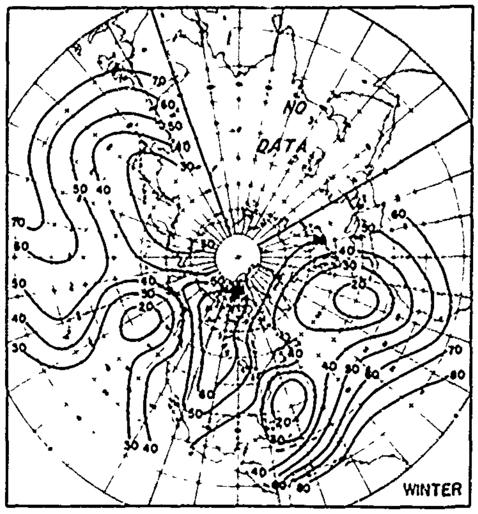
U. S. STANDARD ATMOSPHERE: The attention of the design climatologist, whether at AFCRL or any one of some 30 agencies with a particular interest in this field, never wanders far from the U. S. Standard Atmosphere. The U. S. Standard Atmosphere is a standard unabridged dictionary, the Bible, the basic reference document. As data are accrued by rocket, satellites, balloons and

other sensor-carrying vehicles, the Standard Atmosphere is in process of continuous refinement, improvement, extension. Essentially, it consists of tables setting forth profiles of the thermodynamic properties of the atmosphere, as a function of latitude, altitude and season.

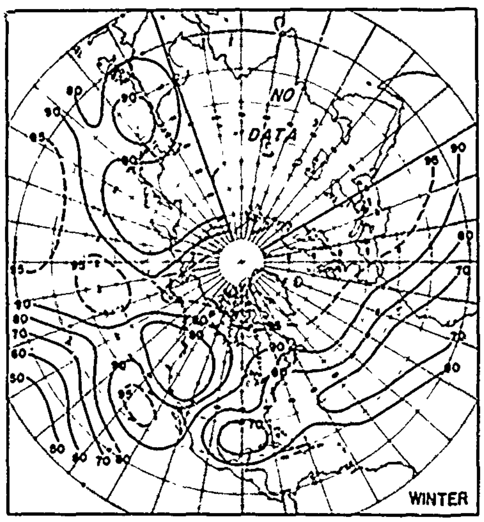
Historically, AFCRL has taken the lead, not only in contributing to the basic experimental data, but also in assuming responsibilities in the compilation and publication of the Standard Atmosphere. The last full volume published was the "U. S. Standard Atmosphere, 1962." In the spring of 1967, a full-scale addition to this volume was published. This work was performed in conjunction with the U. S. Committee on Extension to the Standard Atmosphere (COESA) and published by the Government Printing Office as a companion volume to the "U. S. Standard Atmosphere, 1962." It is entitled "U. S. Standard Atmosphere Supplements, 1966."

During the four-year interim between these major documents, a number of supplemental atmospheres were published under AFCRL editorship or auspices. Several studies were prepared showing the monthly profiles of atmospheric properties through the mesosphere. To illustrate the kinds of data given in the documents, the accompanying figure shows the variation in the range of mean monthly density with latitude and altitude. At the lower left, density varies 10 percent or less in equatorial regions. For the subarctic (upper right) at middle mesospheric altitudes of 60 to 70 km, average monthly density varies by 60 percent or more.

CLOUDS AND LINE-OF-SIGHT: A problem that would seem to have a simple solution is this: What is the probability that the pilot in an aircraft flying at



What is the probability that the ground will be obscured from a pilot's vision by clouds as he looks out at an angle of 30 degrees from 30,000 feet in winter? (Top Chart) What is the probability that the same pilot will see the sky directly overhead? (Bottom) The Laboratory has constructed many charts giving isopleths of these probabilities as a function of angle, altitude and season.



20,000 feet over the East Coast in January will be able to see the ground at an angle of 45 degrees? What is the probability that he will see the ground looking straight down? Or at any other angle? And how do these probabilities change with season?

In terms of a more direct Air Force operational situation, what is the probability that a fighter pilot over North Vietnam will be able to visually track a SAM through partial cloud cover? Or what is the probability that a satellite will see the ground looking at a 25 degree angle? Or straight down?

The approach to the solution of the problem can be rather direct and simple. One can merely record data on the percentage of time that the sun is obscured by clouds at various solar angles. In this case it is not necessary to consider such variables as (in a partially cloudy situation) cloud height, cloud bases, distances between cumulus cells and so on. But when problems arise that do not involve observation of sky from ground or ground from space, as in the case of line-of-sight between two objects at two different altitudes, one is confronted by a new order of complexity.

AFCRL is turning its attention to the more complex problem, although the major part of the effort during the reporting period was devoted to the more straightforward air-to-ground and ground-to-air situation. This program involved some 80,000 observations. The object of this study was to find the percentage of times lines-of-sight from flight altitudes at five angles of elevations were clear or obscured by clouds.

The accompanying figures show two typical maps of the results for winter flights at 30,000 feet. In the first, it can be noted that along the east coast of the U. S. there is only a 30 percent chance of seeing a point on the ground while looking down at an angle of 30 degrees below the horizon from 30,000 feet. In the second, it will be noted that in the same area there is an 80 percent chance of seeing the sky directly overhead. Still this allows 20 percent of the time for not being able to see the sky at this high altitude, much more than had been expected. Extrapolating from the first figure, it appears that there is about a 25 percent chance of not seeing the ground from 30,000 feet over Vietnam.

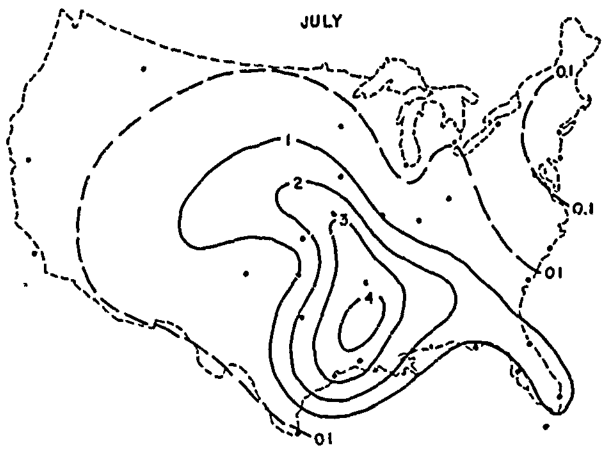
CLOUD HEIGHT AND THE SST: The Laboratory has also analyzed data on clouds that could affect the design of supersonic aircraft. For years meteorologists and those in the aircraft industry have believed that the stratosphere, the SST cruise altitude, would be cloudless and calm. This may not always be the case. Very extensive analysis was given to data obtained from continually operating weather radars. Records from 31 such stations in the United States were available for a period of three years. A typical finding is provided in the associated figure, with the numbers representing percent. The probabilities do not imply continuous cloud cover at 55,000 feet to 60,000 feet. They simply indicate that over the lower Mississippi Valley, for example, there will be at least one cloud penetrating that layer 3 to 4 percent of the time. Even at these altitudes the clouds sometimes have large dimensions.

The significance of this study is this: the range of the SST radar must be extended relative to the range of conventional airborne radars. Otherwise the SST, traveling at Mach 3 speeds, will not have enough time after cloud detection to maneuver around the cloud and thus avoid its turbulence or the sandpapering effect due to precipitation particles.

ATLAS ON ATMOSPHERIC HUMIDITY: During the period, AFCRL published the most comprehensive study on atmospheric humidity that has been issued to date. The study is published in the form of an atlas, with 120 plates devoted to isopleths of water vapor mixing ratios and dew points over the entire Northern Hemisphere. The distribution of water vapor over the Northern Hemisphere is of Air Force interest because of the intense absorption by water vapor of infrared energy. The amount of water vapor present in the atmosphere defines the sensitivity limits of infrared detectors.

Data for the atlas were drawn from 1500 surface observational sites and 400 upper-air radiosonde stations distributed throughout the Northern Hemisphere. More than 60 percent of these were on the Eurasian mainland. At each station, dew point data over a five-year period were taken. (Water vapor is measured in terms of dew point, the temperature at which air becomes saturated when cooled without addition of moisture or change of pressure.)

Water vapor of course varies with altitude and with season. But even within a season (or from day to day, for that matter) there are wide variations. The atlas takes all this into account. Data for only four midseason months—January, April, July and October—were compiled. For each of these months isopleths were plotted for four pressure levels. These pressure or millibar levels are 850 (4700 feet), 700 (9800 feet), 500 (18,500 feet), and 400 (23,600 feet). But the average monthly values alone at these various layers is a rather coarse index. A set of percentiles representing the frequency distribution of the moisture content, level by level, gives a more meaningful picture. Therefore, at each level for each of the four months, separate isopleths are plotted on the percent of the time one would expect to find a given dew point. Percentiles chosen were 5, 25, 50, 75 and 95. Twenty of the 120 charts consist of isohumes of mixing ratio at the surface of the earth.



An SST pilot should, according to this chart, expect to observe and possibly dodge at least one cumulus cloud extending above 55,000 feet four percent of the time during July in the Louisiana area. Probabilities of sighting such high level clouds across the U.S. are shown.

OTHER STUDIES: A statistical method for deriving persistence and variability of meteorological parameters from one hour to a full month was formulated. This method has been tested with such meteorological elements as temperature, dew points, cloud cover and height, precipitation, and wind speed at the surface and aloft. It gives the probability that critical conditions will be exceeded for specific number of hours, probability that an event lasting a specific number of hours will occur, and probable frequency of critical events in a day, a week or a month. An example of the kind of problem that the statistical tool is used

to solve is the probability that at a certain location an upper wind would exceed a critical speed of 40 knots after a balloon has been tethered, contingent upon speed occurring at the time of tethering. In this example, the results would show that if the speed were 28 knots when tethered there is a 50–50 chance of the speed remaining below 40 knots seven or eight days. The 95 percent probable life is only eight hours. If the speed at launch were only seven knots there is a 95 percent likelihood of clear sailing for nearly two days.

A substantial field program is devoted to the measurement of turbulence in the 30 to 60 km altitude region. A special study of 18 falling plastic spheres released in pairs over a six-hour period revealed that wavelength of gravity waves is probably three times as long as had been theoretically speculated. Certain preliminary smoke puff and smoke trail data were analyzed for various scales of turbulence taking place at these altitudes. The accompanying figure shows the distortion of a trail in the 38 to 41 km altitude range that took place over a five-second period.

Climatologists have long believed that many years of data are needed to give a valid mean representative of true climate. However, when that mean is used to suggest future conditions, rather than describe past ones, this principle may not apply. The best estimate of the winds likely to be encountered by a reentering missile may be derived by averaging data only over a four to six year period rather than over a longer period. In general, the study shows that next year's winds will be closer to the average of the last five years than to the ten-year or 15-year average.

The design climatology group serves the Air Force and its contractors as the primary center for climatological data. During the report period, more than 50 formal requests for technical information were received and answered. A typical problem was to evaluate the possible existence of a density discontinuity in the mesosphere which might have been responsible for certain observations during tests of a reentry aerospace vehicle.

METEOROLOGICAL EQUIPMENT

The data upon which the design climatologist draws for his analyses derive from a multitude of meteorological equipments employed operationally—storm radars and other ground-based sensors and probes, and small sounding rockets and balloons. Both the meteorological sounding rockets and the balloons are of a different breed from the rockets and balloons covered earlier in this chapter. Here the emphasis is on rockets designed to carry relatively simple packages of a few pounds and balloons measured in diameters of a few feet.

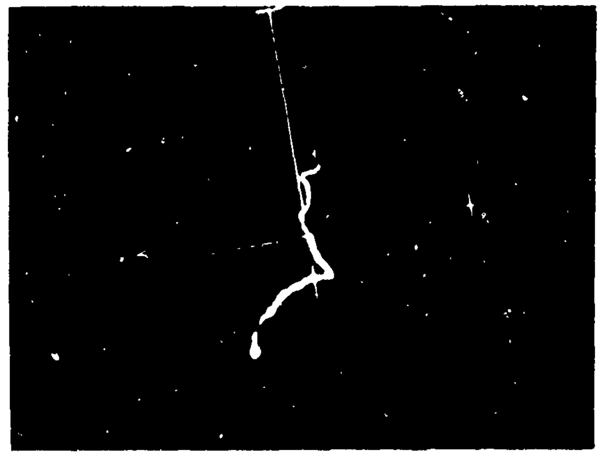
The equipment under test and development by personnel in the meteorological equipment program is often only a half-step removed from field operation. Thus, the coupling between this program and the Air Weather Service is broad and direct. There are also close ties to the Air Force Systems Command. An example was an engineering mission by a member of the group to the Far East in 1966, at the request of these two agencies, to check out the installation of the AFCRL-developed vertically pointing radar set AN/TPQ-11 and the Weather Bureau's storm detection radar set, the WSR-57.

Another point of interest is the close-knit fraternity of Government agencies

concerned with meteorological equipment. This relationship leads to the frequent cross-procurement of equipments and sharing of development costs. The AFCRL activities described below illustrate this point.

SOUNDING ROCKETS: A miniaturized rocket sounding system known as the LOKI-DART or the PWN-8A, developed under AFCRL supervision, was accepted for routine use at the test ranges and in the Meteorological Rocket Network. The Laboratory procured the first operational quantities of this system and was at the conclusion of the report period finishing up the complex data package required for large-scale competitive procurement by the Logistics Command. This effort includes qualifying a slightly more powerful booster vehicle than the LOKI. The PWN-8A, with its much lower cost and less restrictive launching conditions, measures temperature, density and wind to 60 km. It employs a transmit-only sonde, ejected at apogee. Efforts to develop a transponder sonde for this system have been encouraged by the success of the AN/DMQ-9 transponder sonde in operational use with the larger ARCAS rocket.

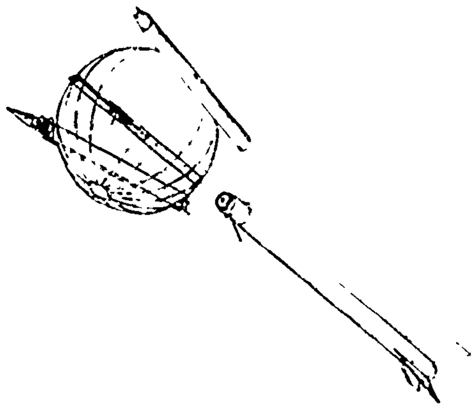
Excessive fall velocities and wild oscillations of the sonde after ejection degrade rocketsonde data. To alleviate this problem, the Ballute, a ram air-inflated retardation and stabilization device combining the aerodynamic advantages of the balloon and the parachute, was substituted for the usual parachute on many LOKI and ARCAS flights. There was a dramatic improvement in data quality and an encouraging decrease in fall rate. New parachute designs, such as NASA's Disc-Gap-Band parachute, are also being investigated.



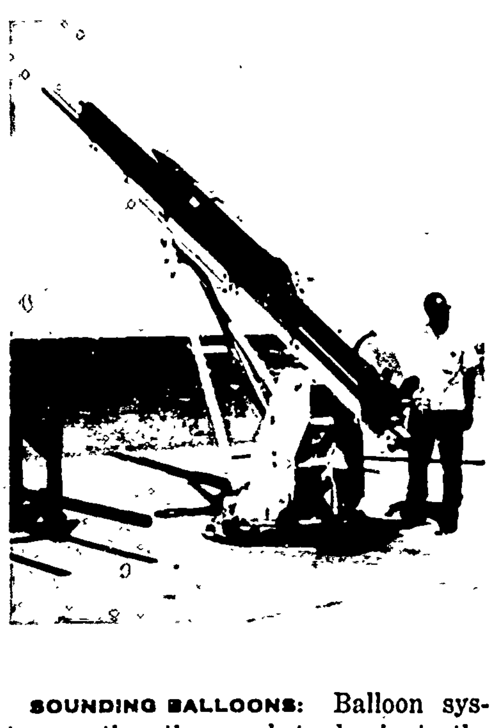
The most direct way to measure upper atmosphere winds and turbulence is to release a stream of smoke by a rocket and to observe the configuration assumed by the smoke trail.

The ARCAS and LOKI classes of sounding rockets have an effective apogee of 60 to 65 km. This is low relative to stated requirements which extend to 200 km. A low-cost, high-altitude rocket is consequently under consideration. Unfortunately, the logarithmic profile of atmospheric density restricts the altitude range over which any one sensor can operate; and the resultant proliferation of sensors has complicated the task and thus adds weight and cost. One candidate that can accommodate the added weight is the SPARROW-ARCAS which has performed well to 150 km. Another, the limited payload 140-km VIPER-boosted dart, is being readied for test.

A low-altitude rocket sounding system, the CRICKET, is also being tested with a view towards use in Vietnam. This is a cold-propellant rocket with a 3000-foot apogee. It is designed for recovery and therefore a single CRICKET can be used repeatedly.



The free-fall inflated sphere containing a triaxial accelerometer is a standard technique developed by AFCRL for measuring atmospheric densities. During the reporting period, this basic system was redesigned for use in smaller, less expensive Sparrow-ARCAS rockets (below). The system can be used to measure densities at altitudes from about 130 km down to 70 km.



SOUNDING BALLOONS: Balloon systems rather than rockets dominate the meteorological sounding field because of balloon simplicity, minimal launch requirements and low cost—a few dollars as against several hundred dollars for a rocket. Hence, the Laboratory devotes considerable time to balloon system improvements, seeking faster rise rates, better cold temperature performance, higher altitude capabilities, more reliability, and better tracking and telemetry techniques.

A joint AFCRL-Army balloon material research program has steadily improved neoprene film performance. This has been needed especially for the cold nighttime temperatures of the arctic winter stratosphere and those of the tropical tropopause. The new ML-607 balloon, containing more plasticizer to reduce film brittleness, was tested in the Canal Zone and in Greenland during the 1965–1966 winter and should soon become the first true 110,000 foot, day-night, all-zone standard.

The two-piece, streamlined ML-566 fast-rise balloon (approximately 1700 feet/min) was developed with the Army to provide atmospheric profiles more nearly in real time and to eliminate low angle rawin set errors. The Laboratory is now attempting to reduce its high cost.

Support was given to a novel Army-developed in-flight chemical heater designed to keep the balloon film warm and to provide additional lift, thus improving rate of rise and altitude capability. Many flights were made with experimental high altitude balloons of more conventional design in an attempt to develop a standard 135,000 foot balloon.

Concurrent with the foregoing developments have come advances in miniaturized payloads, in higher data sampling rates and in more accurate ranging.

SOUNDING INSTRUMENTATION: As higher altitude rockets and balloons are

developed, the performance of the meteorological sensors they carry becomes less reliable. This means that a new generation of high altitude sensors must be developed. Most of the effort is placed on sensors for measuring temperature and atmospheric density. Historically, however, AFCRL strongly emphasized the development of humidity sensors, one of which (the Alpha-Radiation Dew Point Hygrometer) has now passed into the realm of a standard device.

The AFCRL sensor program has several related aspects: 1) to design basically new types of sensors; 2) to improve the performance of existing sensors, both in sensitivity and in response-time, the latter being an essential feature in sensors carried aboard a vehicle that ascends rapidly through a changing environment, and 3) to define systematic errors in particular sensors which has the effect of upgrading the quality of data from an otherwise unsatisfactory sensor.

This work has too many parts to warrant a fair and meaningful discussion of each. Discussion will be limited to only one atmospheric parameter where most in-house research is concentrated; namely, atmospheric density, and methods for deriving density data above about 65 km. During the reporting period, five different techniques for measuring density were under investigation. Three of these involve falling objects and the measurement of the drag upon these objects.

The ROBIN sphere with interior corner reflectors for radar tracking from the gound has been used for many years to measure density. Its effective altitude, however, has been limited to about 60 km. AFCRL has redesigned the ROBIN to measure densities up to 100 km. The redesigned sphere has been flown experimentally on SIDEWINDER and SPARROW-boosted ARCAS rockets.

Density data from still higher altitudes were obtained by means of another AFCRL-designed sphere containing an accelerometer. This three-foot diameter, inflatable sphere has provided good data up to 150 km. The accelerometer data are telemetered to the ground. A two-foot diameter version of this sphere, capable of measurements up to 130 km, was partially instrumented and tested using a SPARROW-ARCAS rocket. The electronics of this smaller system will eventually permit rawin set tracking and ranging. The prototype of a "spin-rate decay" density sensor with plastic rotors was designed and readied for test. Work was begun on a second generation version of this sensor which employs an array of spinning wires.

Two non-drop types of density sensors are under development. One measures fluorescence induced by collisions between atmospheric molecules and a high

The ballute combines a balloon and parachute in one vehicle. It was designed by AFCRL to support rocketsondes ejected at high altitudes from meteorological sounding rockets. It allows the rocketsonde to descend at a slower rate and with considerably less oscillatory motion.

energy electron beam. The second is a ram pressure density probe similar to one used experimentally on the X-15 aircraft.

AIRCRAFT-BORNE SENSORS AND CAT: Of meteorological sensors designed for aircraft use, clear air turbulence detectors have received most attention in recent years. AFCRL has a great deal of company in these investigations. Many research groups all over the country are working on the CAT problem. Nor is AFCRL's work confined to the Aerospace Instrumentation Laboratory. The Meteorology Laboratory (Chapter VI) is studying the mechanisms of CAT formation and methods for detecting it, using ground-based weather radars.

One effort of the Aerospace Instrumentation Laboratory centers on an attempt to obtain objective measurements of turbulence intensities. One way to measure intensities is to fly an aircraft through turbulence and measure the resulting shock. But the severity of the shock is to a large extent dictated by the particular aircraft used and its speed. The response characteristics are different for each aircraft type. AFCRL has initiated development of a sensor to be placed aboard Air Weather Service aircraft for objective measurements of turbulence. The development is based on earlier NASA work and provides readings which are independent of the type of aircraft used.

Several different approaches were taken in the search for a suitable remote detector of CAT. Test results have not been particularly encouraging—but they haven't been altogether discouraging either. One study established the feasibility of CAT detection by laser doppler techniques. In another study, AFCRL supported the University of Michigan's use of a T-29 aircraft in airborne laser detector experiments. An infrared radiometer, operating in the 15 micron CO_2 band was acquired to investigate techniques of measuring free air temperature and temperature gradients. Characteristic changes in temperature gradients may provide clues to approaching CAT. A smaller, less sophisticated version of this radiometer has been installed on a high performance sailplane.

The Laboratory also sponsors an arrangement for five commercial jet airliners to carry low frequency, electric field emission detectors and recorders to see if such emissions might provide a warning of CAT.

Other airborne meteorological sensors include an air-dropped windsonde permitting wind measurements to be made from the air over oceans and other inaccessible areas. The basic element in this windsonde is a gas-bearing gyro. This development is aimed at a long time goal of Air Force meteorology, to provide a vertical wind profile below an aircraft.

Still in the study stage is a radiometric technique for making remote measurements of the vertical profile of temperature, pressure, and humidity from an aircraft.

SURFACE OBSERVING INSTRUMENTATION: In this concluding segment, five discrete projects are noted. The first two of these (atmospheric electricity detection and tracking ionized trails of meteors) have been in progress for about four years. The remaining three were undertaken during the present reporting period.

For obvious reasons, electrical storms and severe atmospheric electricity can seriously endanger Cape Kennedy launch operations. Since 1963, AFCRL has conducted research in the Cape Kennedy area on a system for detecting and tracking areas of severe electrification. The

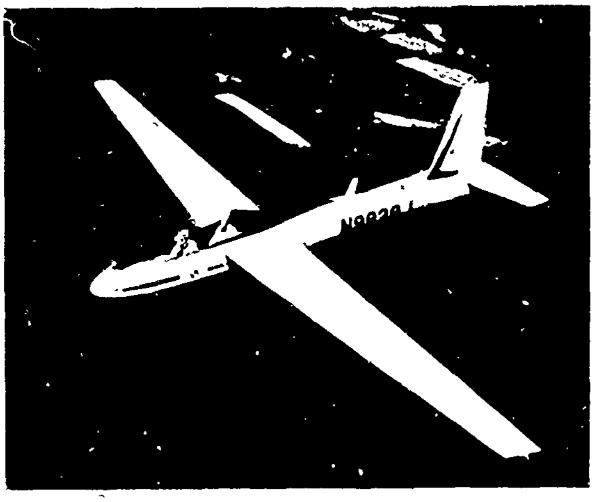
system has been designated "SPARSA." During the reporting period, the SPARSA equipment was redesigned, resulting in a substantial improvement in the system's detection and tracking capabilities.

Another program that had been in progress for several years was completed. This is a system for measuring upper atmosphere wind speeds in the 80 to 96 km region by tracking the ionized trails of meteors entering the atmosphere. The system was designed for use at the Smithsonian Astrophysical Observatory's site at Havana, Illinois, under laboratory contract. It was originally planned as a system for measuring both wind speeds and atmospheric density. However, hopes with respect to density measurements have dimmed. Density data were to be derived from the rate of expansion and diffusion of the ionized trail, but the lack of homogeneity in the trails appears to make this impossible.

AFCRL and the Coast Guard joined to support, under contract, the development of a lightweight backscatter visibility measuring system, which has progressed through the prototype stage. The device employs a gallium arsenide monochromatic light source, is portable and can be battery-powered.

A new pulse-type sonic anemometer proved to be extremely responsive up to winds of 75 knots. An effort to refine the design by eliminating occasional ringing and by incorporating integrated circuits in the associated electronics is nearing completion. This anemometer is intended primarily for test range use to measure short-period gusts.

In another approach to the measurement of upper atmosphere densities from the ground, a laser searchlight is used. In work carried out under AFCRL contract by the University of West Indies, the technique was shown



During the period, a glider was instrumented by the Laboratory for studies of infrared patterns and other phenomena associated with clear air turbulence.

This pulse-type sonic anemometer has proved to be extremely sensitive to winds as high as 75 knots. Wind speed is measured by detecting variations in an acoustic signal transmitted into the space between a sonic emitter and detector. Three emitter-detector pairs are seen here.

to be usable up to altitudes of 60 km. At the conclusion of this reporting period, researchers were attempting to extend the laser searchlight capability to 100 km.

The work reported here does not fully encompass the work at AFCRL devoted to ground-based meteorological instrumentation. Research on weather radar, surface fog detectors, and other equipments is conducted by AFCRL's Meteorology Laboratory whose program is discussed in the following chapter.

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VI Meteorology Laboratory

The program of AFCRL's Meteorology Laboratory has the ultimate goals of more precise and longer range weather forecasting and of weather modification. The program has three distinct aspects: 1) the development of improved sensors and analytical equipment, 2) gathering, by means of highly advanced equipments, more precise data on meteorological phenomena, and 3) advancing the theoretical understanding of the factors that combine to create particular weather events.

Encompassed within these aspects are the development of improved weather radars and associated processing equipment, studies of transport processes from the stratosphere across the tropopause into the troposphere, observations of clouds and severe storm systems, the prediction and detection of clear air turbulence, investigations of techniques for fog and cloud dissipation, studies of the general atmospheric circulation, measurements of ozone concentrations in the upper atmosphere, and the analysis of weather satellite data.

The Laboratory operates both permanent and temporary field sites for these investigations. The largest permanent site is a weather radar facility at Sudbury, Massachusetts. Another permanent site, operated jointly with NASA, is a radar facility at Wallops Island, Virginia, where studies of clear air radar echoes and of the feasibility of using radar for the detection of clear air turbulence are conducted. On a broad, flat one-square mile area in the center of a Kansas wheatfield, the Laboratory operates a facility for micrometeorological research, or research into

meteorological phenomena with scale dimensions of less than one mile.

During the period, AFCRL used three aircraft for meteorological research—a C-130, an F-100F and a U-2. The U-2 aircraft had been used since the late 1950's and proved to be an extremely valuable facility for making observations from high above major weather systems. In 1966, the U-2 was withdrawn to be used by the Air Force for other purposes. The C-130 aircraft, highly instrumented with a variety of sensors for close observations of important parameters associated with weather systems, saw wide use during the period. Each summer, Laboratory scientists take the aircraft to Florida to observe the unique weather structure over the Florida peninsula, a program that grew in importance during the period because of the Department of Defense's interest in tropical meteorology.

The Laboratory's large staff of internationally recognized scientists, active participants in the meteorology research community and in profe ional societies, provide the Air Force with a broad interface with this community. The Laboratory gives the Air Force a reservoir of talent to draw from for advice and to staff special study groups.

One of the goals of the research of this Laboratory deserves special commentary—namely, that of weather modification. Fog and cloud dispersal is a form of weather modification that is clearly in the interest of Air Force operations. But modification on a larger scale is a matter of national and international import, and thus a political matter. The knowledge growing out of seemingly unrelated research on atmospheric processes by AFCRL and others is a necessary precondition to the development of techniques for weather modification where, when, and if it is deemed desirable. Two features are important in the consideration of modification schemes. One involves the vast energies associated with all weather systems, even the most benign; the other involves the instability of atmospheric processes giving rise to weather systems. The key to weather modification and control is the early detection and identification of incipient instabilities because it is at this stage that man can intrude to dissipate, induce, or augment the instabilities that trigger weather. The goal is feasible, but far distant in most cases.

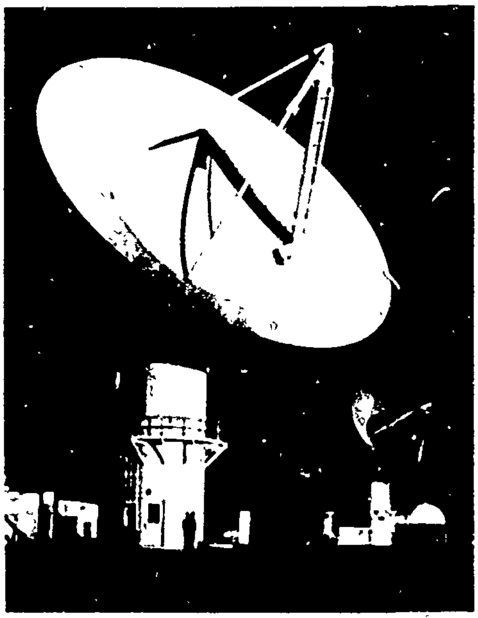
AFCRL's weather radar site is located at Sudbury, Mass., about 15 miles from the main AFCRL laboratories.

WEATHER RADAR TECHNIQUES

The weather radar program at AFCRL is centered at two locations. The primary center is the weather radar site at Sudbury, Mass., where work is focused on the observation of precipitation systems and on the development of better weather radar and display systems.

Here local thunderstorms and large convective systems are observed to learn more about their structure and dynamics and to deduce the fields of vertical and horizontal winds, wind variability, and moisture content. Four weather radars are in operation at Sudbury. Two of these, a 10-cm FPS-6 and a 3.2-cm CPS-9, are standard radars, although experimental modifications have been made to each. The third radar is an experimental APQ-70 system, operating at 1.86 cm. The fourth radar is a nonstandard radar, transferred from Lincoln Laboratory several years ago, and designated the Porcupine Doppler radar.

The second site is relatively new (for AFCRL) and is located at Wallops Island, Virginia. It is operated as a joint AFCRL-NASA facility. Prior to AFCRL's assuming responsibility for its operation in 1965, it was used by the Lincoln Laboratory for missile reentry research. At the site are three high-resolution radars operating respectively at 71.5, 10.7, and 3.2 cm. Dish size for the first two is 60 feet; for the third, 34 feet. During the reporting period, about half of the total effort of AFCRL's weather radar group involved experiments at Wallops Island. The very sensitive Wallops Island radars were used to observe atmospheric structure and phenomena, the most important of these being clear air turbulence. Wallops Island experiments are discussed under the following three headings.



Radars at Wallops Island, Virginia, were extensively used by AFCRL for CAT studies. The antenna in the foreground has a dual feedhorn and operates in the 71 cm and 3.2 cm wavelength regions. The antenna in the background operates in the 10.7 cm wavelength region.

RADAR DETECTION OF CAT: Using the high-resolution radars at Wallops Island and uninstrumented jet aircraft, scientists from AFCRL and the Applied Physics Laboratory, Johns Hopkins University, have probed regions of the clear atmosphere in search of high-level turbulence. All regions of clear-air radar echoes above 6 km which were probed simultaneously with the aircraft were found to be turbulent.

The three ultrasensitive Wallops Island radars, used in concert, make it possible to distinguish between clear-air radar echoes and those echoes caused by clouds, precipitation, or any other types of particulate matter. The clear-air echoes arise because of scattering from variations in refractive index. They are seen most strongly with the 10.7-cm (S-band) radar. This set has a beamwidth of 0.48 degrees and a peak power output of 3 megawatts. Although clear-air echoes are often observed in the lower troposphere, clear-air radar layers have also been observed from the upper troposphere and from the tropopause, the level marking the upper boundary of the troposphere and the lower limit of the stratosphere.

The clear-air radar echo intensity is dependent both on the magnitude of the mean vertical gradient of refractive index and, in a complex manner, on the severity of turbulence. The large vertical gradients of refractive index which frequently exist in the lower troposphere are detectable even when the turbulence within the region is much too small to affect aircraft. In the upper troposphere, however, the vertical gradient of refractive index is limited because of the almost negligible amounts of water vapor present in the atmosphere at high levels. Under these circumstances, turbulence sufficiently intense to affect aircraft is necessary before the region at the tropopause level was detectable by radar.

CLEAR AIR CONVECTION PATTERNS: In experiments related to CAT observations, AFCRL used the Wallops Island radars to observe the clear air convection patterns below 20,000 feet to determine their relationship to cloud formation.

In the early morning, a thin horizontal clear-air layer is usually observed near the surface. Several thin stratified layers may be detected at higher altitudes. As surface heating continues, the surface layer rises and breaks up into convective patterns consisting of several convective cells with almost vertical boundaries. At this stage the cells have not yet become clouds, but they do appear clearly on the radar scopes. As the convection continues the moisture reaches saturation levels and clouds develop. The close connection between the clear-air convective patterns and the later development of both convective and stratiform clouds is obvious.

In the afternoon, during the decaying stage of the convective process, the clouds dissipate but radar echoes persist for up to two hours in the region previously occupied by clouds. The decay of clear air structures starts at the higher altitudes and proceeds to the lower levels. The observations suggest that the evaporation of cloud droplets and the creation of humidity gradients are important for the persistence of the clear-air patterns well after the convective forces are suppressed.

The clear-air convective cells preceding cloud formation are about one to five km in diameter, have maximum updraft speeds within their centers, and have lifetimes of at least ten minutes. Usually, the cells are aligned with the wind, but, on occasion, there is evidence that a group of cells will form around the circumference of a circle whose diameter is in the order of ten km.

In a related study, a Lane refractometer was installed in a helicopter performing ascending and descending spirals as well as straight, porpoising, or constant altitude runs. The helicopter position was evaluated from tracking data to permit an accurate comparison of refractivity data to radar displays. A one-to-one correspondence between main refractivity disturbances and clear-air returns was revealed.

ANGELS, BIRDS AND BEES: One class of spurious radar targets—known as "dot angels"—has been attributed to three sources: birds, insects and atmospheric refractivity perturbations. A previously unresolved question is just how much each contributes to the dot angel problem.

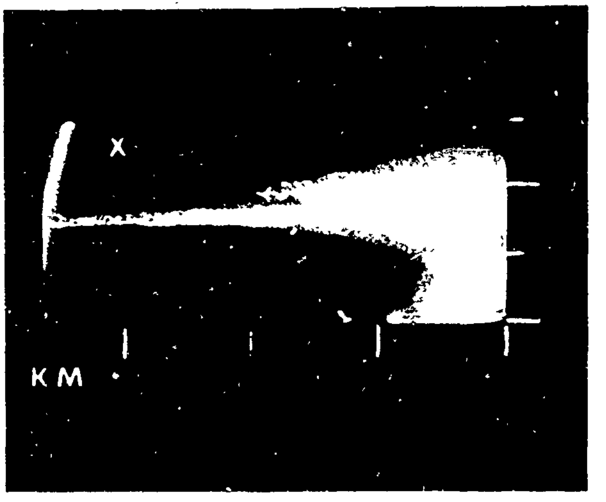
In experiments using the Wallops Island radars, it has been found that for the most commonly observed dot angels, insects are the sole contributors—not swarms of insects, but single individual specimens. Assisting AFCRL in the experiments were scientists from the

Applied Physics Laboratory, Johns Hopkins University, and entomologists of the Department of Agriculture.

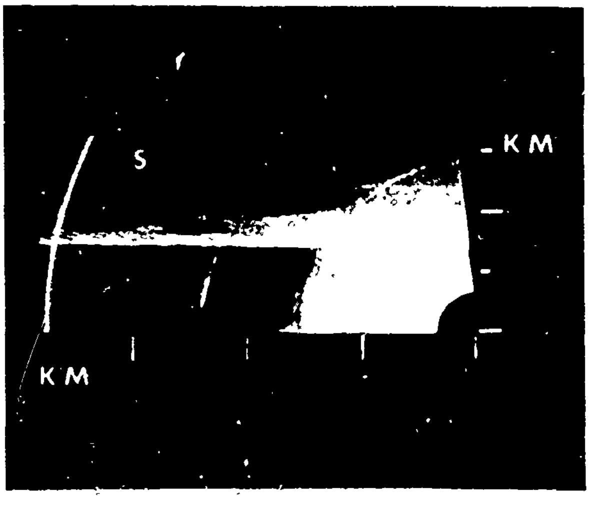
The experiments, which began in September 1965, were fairly straightforward. In a typical experiment, a honey bee was fed sugar water (for energy), taken to an altitude of about 5000 feet in a small single-engine aircraft and dropped overboard. One or more of the three Wallops Island radars, about seven miles away and pointed toward the drop zone, picked up the small target. The horizontal and vertical flight path of the insect was then plotted.

Analysis shows differing kinds of radar returns from different insects. The flight of the hawk moth, for example, results in two kinds of fluctuations. The wing beat causes a large amplitude fluctuation. A less distinct oscillation pattern occurs when the insect is tumbling in free fall. In addition to the hawk moth and the honey bee, a tobacco budworm and a dragonfly were tested. Release altitudes varied from 5000 to 10,000 feet. Of the insects tested, the honey bee proved of most interest. The honey bee is a strong flyer capable of maintaining a velocity of more than 20 feet per second relative to the wind for exceptionally long periods of time.

Similar studies were conducted by the Applied Physics Laboratory with birds —pigeons, grackles and sparrows. Birds are easily identified as birds on a radar scope. There is a strong wavelength dependence. Radar reflections from birds are most pronounced at 10 cm. Over the years, radar cross sections of birds have been extensively measured and provide a large body of cross-section data to draw upon. Because birds can be readily identified, the problem was narrowed to the question of the relative contributions of insects and of refractivity surfaces to the dot angel phenomenon.



These two photographs were taken simultaneously of X band and S band radar scopes. The strong, dominating echoes at 7 to 11 km in both the X and S band scope photos are due to cirrus clouds. The thin layer at 12 km on the S band photograph (indicated by arrow) is a radar echo from clear air.



The long wavelength relative to specimen size precludes the detection of insects by radars operating at wavelengths of 71.5 cm or greater. In measuring the radar cross section of insects at 3.2 and 10.7 cm, the AFCRL experimenters

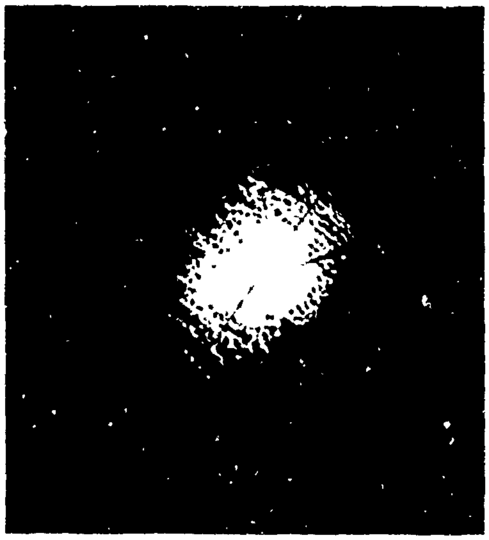
found, as in the case of bird observations, a strong wavelength dependence, this ranging from inverse first to the inverse third power of the wavelength. It was this wavelength dependence that removed the ambiguity between angels caused by insects and refractivity structures. In a separate analysis, it was shown that no conceivable atmospheric structure could be the source of dot angels if the wavelength dependence was less than the inverse second wavelength. Thus, for one major class of dot angels, all are caused by single insects in free flight.

The AFCRL scientists were interested in resolving a particular type of radar problem—namely, that of dot angels. The interests of the Department of Agriculture entomologists assisting in the program were in another direction. In these studies they saw the potential of an important new research tool, permitting entomologists to obtain information on insect behavior heretofore unobtainable. The studies show that it is possible to track insects by radar at relatively great distances and to observe their flight patterns and migrations by radar.

WEATHER RADAR RESEARCH AT SUDBURY: The four weather radars and their associated processing and display equipments at AFCRL's Sudbury, Massachusetts, site define, in effect, the limits of the present state of the art in weather radar capability. The program at Sudbury is a dual one. The development and test of new or modified equipment is inextricably mixed with observational studies of the internal dynamics of convective storms. Development aspects of the program are concerned with display, spectral analysis, and processing of Doppler radar signals; development of dual-beam incoherent radar techniques for measurements of tangential wind velocities and refinement of signal integration techniques.

The observational-interpretational aspect of the program deals with the description of the internal structure of storm systems—wind field, moisture content, precipitation particle size, and so on. Thunderstorms and other storm systems in the New England area are, of course, randomly occurring and sometimes widely spaced events, and as such, represent targets of opportunity. But each event can be recorded on film and magnetic tape for experimental processing under a range of varying test conditions.

Doppler radar investigations of convective storms are complicated by an ambiguity of interpretation. For example, observed Doppler velocities are a sum of radial components from particle fall speeds and from horizontal and vertical air motions. Except at very small



This radar scope photograph was taken at mid-morning on a cloudless day. Clear air convective patterns are clearly seen out to a range of 50 miles.

elevation angles, the two contributions to Doppler velocity may be of comparable magnitude. Various assumptions have been invoked in an attempt to overcome this inherent difficulty. For example, it has been suggested (Rogers) that there is a relationship between mean raindrop fall speed and radar reflectivity. Another assumption (Battan) was that the spread of vertical Doppler velocities is a function primarily of the distribution of drop sizes and their corresponding fall speeds.

However, in one particular thunderstorm observed by AFCRL there were regions of unusually broad spectral width but only moderate reflectivity, pointing toward an inconsistency between the Rogers and Battan approaches. These broad velocity spectra occurred along the edges of a major updraft where there was also maximum shear in updraft speed. Strong shear would tend to narrow the particle size distribution by sorting the particles according to fall speed. Furthermore, shear alone cannot account for the abnormally broad spectral widths. The observations, therefore, indicate that turbulence is an important cause of the very broad velocity spectra, and suggest the utility of Doppler radar measurements of the vertical velocity spectrum as an indicator of severe cloudy-air turbulence. Also, the observations point out the inherent difficulty in determining particle size distributions in thunderstorms from measurements of the Doppler velocity spectrum.

CLOUD PHYSICS

The research covered in this section deals with the evolution of clouds and the processes that initiate their formation. This description includes the study of cloud populations and their development and patterning in time and space, warm and cold fog formation, methods of dissipation, and thunderstorm electricity. The overall cloud physics program has several balanced parts—instrumentation, observation, data reduction and analysis, and theoretical interpretation.

Much of the instrumentation used for these studies is non-standard, entailing the custom-development of measuring devices, probes, and sensors. Because the large amounts of data gathered under the cloud physics program create, in turn, a data analysis problem, special emphasis is given to computer programs for the automatic processing and analysis of the data. This has resulted in a number of special computer programs by the AFCRL computer facility.

Three aircraft—a C-130, an F100F and a U-2—were used extensively during the reporting period. The C-130 aircraft was the basic data-gathering facility on most of the Laboratory's field trips. The interior of this aircraft was completely refitted during the reporting period and many new instruments installed. Among the new equipments are refractometer converters, circuits for coordinated time coding from all equipment, digital and analog tape recording systems, and displays. In addition, the aircraft carries various temperature probes, electric field meters, and exterior ducts for sampling atmospheric liquid-water content and atmospheric humidity. The aircraft carries three cameras for mapping terrain and horizon-to-horizon cloud cover and four 16mm time-lapse cameras used to record the growth of clouds.

AFCRL meteorologists and their instrumented aircraft are usually called upon to participate in large national

This huge, hail-bearing cumulus cloud was photographed from AFCRL's C-130 aircraft over South Dakota in June 1966 from an altitude of about 26,000 feet.

observational programs involving several agencies. For example, a new program concerned with hailstorm modificat'on (Project Hailswath), sponsored by the National Science Foundation, was started in the summer of 1966. AFCRL, together with NCAR, the Army, the Navy, ESSA and many others are participants in the program designed to develop techniques for the ''ification of these destructive storr ''

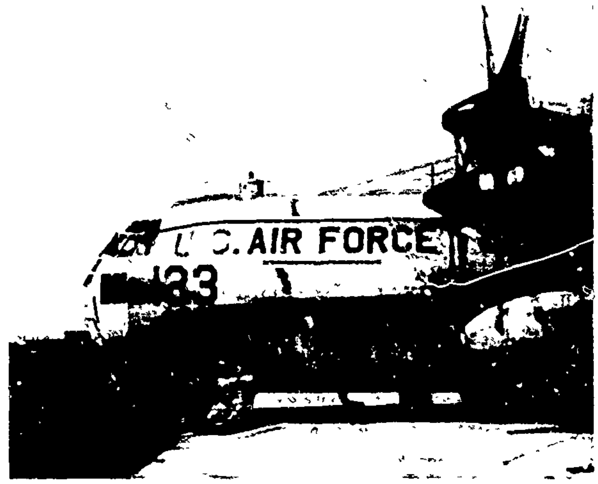
SEVERE LOCAL STORMS: The hailstorm modification program noted above is typical of cooperative programs involving many agencies, many instruments, many observers, and many skills. Another such program is one concerned with severe spring storms which occur in southwestern Oklahoma.

On May 26, 1963, a family of severe local storms occurred in that area. Rarely has a family of storms been observed with such a variety of instruments and by so many qualified people,

including eight AFCRL meteorologists. Meteorological equipment included a TIROS satellite, weather radar, several aircraft, including AFCRL's C-130 and U-2, and standard monitoring equipment for measuring pressures, winds, humidity, and temperatures arrayed over widespread areas. Rainfall was collected for later analysis of radioactivity, and giant hailstones were gathered and placed in deep freeze for laboratory examination.

The results of these observations were compiled by an AFCRL scientist in a 16-chapter report published by AFCRL in December 1965 entitled, "A Family Outbreak of Severe Local Storms—A Comprehensive Study of Storms in Oklahoma on 26 May 1963." The family of storms on May 26 began to form along a cold front southwest of Oklahoma City about 1 p.m., and moved in an east-northeasterly direction. Eleven individual storm cells comprised this family, and the tops of their towering cumulonimbus clouds merged together to form a giant anvil canopy at altitudes between 30,000 and 50,000 feet. A number of these storms produced giant hail and tornadoes. Observers on the ground were able to watch the formation and behavior of two of these awesome funnel clouds. From the extensive observations, detailed models of precipitation trajectories and airflow patterns were derived.

The conclusions contained in the report are too numerous to summarize here, but generalizations can be made. Severe local storms are quite different from non-severe storms. They are not merely scaled-up thunderstorms, but have a character all their own. One of the primary ways in which this difference is manifested is in the life cycles of these two types of storms. An ordinary storm passes through three stages: the cumulus, or formative stage; the ordinary mature stage; and the dissipating stage. The severe storm, initially comprised of several subcells, evolves into a large and sometimes persistent single cell after reaching the mature stage. It is during this stage that tornado activity, characteristic of the severe local storm, develops.



The primary facility for AFCRL's cloud physics research program is this C-130. It is instrumented with a variety of sensors.

THUNDERSTORM ELECTRICITY: The probable cause for several commercial aircraft crashes has been attributed to thunderstorm electricity—lightning. Lightning is a source of danger in all Air Force aircraft operations. Just how do lightning discharges to an aircraft affect the integrity of the aircraft, its instruments, and its weapons systems?

To answer this question, the Meteorology Laboratory conducted a large experimental program involving its three instrumented aircraft. These aircraft, during the reporting period, flew several hundred flights consisting of coordinated patterns around, through, and above particular storms. A scientific objective of this program was to determine

Lightning is seen striking an F-100 aircraft during penetration of a Florida thunderstorm. Several hundred penetration flights were made by AFCRL to learn more about the formation of electrical storm centers in convective clouds.

the processes responsible for the formation of electrical charge centers in convective clouds. Other interrelated objectives were to measure the current flow above thunderstorms, to determine the relation of this current flow to the electrical charge of the earth, and to correlate electrically active portions of the storm with areas of turbulence and precipitation.

Most of the flights made during the period took place in Florida where summer electrical storms are frequent. Penetration flights were made with an F-100F. In 608 minutes of thunderstorm flight extending over several months, the aircraft was struck by lightning at least 33 times. On some of the flights. the lightning striking the aircraft was essentially the only lightning to occur during the penetration intervals, suggesting that the presence of the aircraft actually triggered the lightning stroke. Curiously, on other penetrations this triggering feature was not found. This suggests that some characteristic difference in storm properties may exist between different thunderstorms or at different stages of thunderstorm development. The Laboratory is seeking to identify these differences and to explain why they occur.

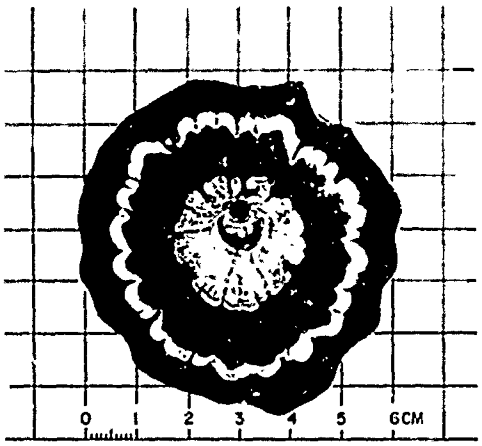
Of the 33 lightning strikes encountered by the penetration aircraft, successful current measurements were accomplished on 24. Electrostatic field and aircraft charge fluctuations were measured on most of the strikes.

The mean horizontal dimensions of continuous electrostatic field disturbance was 36 km with a standard deviation of 25 km. Maximum measurable electrostatic fields on the aircraft surface were up to 390,000 V/m. Sixty-nine percent of the strikes occurred when surface fields were less than 120,000 V/m.

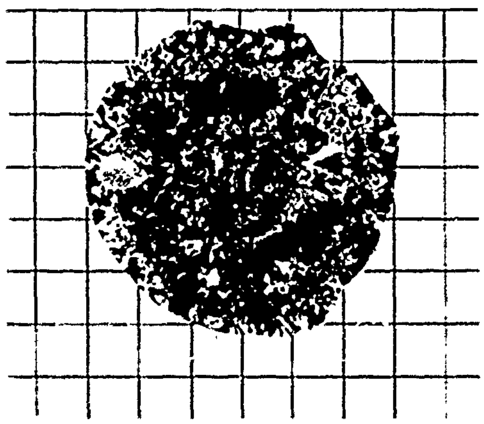
The penetration flight data obtained by AFCRL permit construction of a lightning strike vs. altitude probability distribution curve for aircraft operation. The curve when extrapolated to the ground agrees well with surface measurements. This curve has also been extended upward to supersonic transport altitudes using data from the U-2 aircraft taken during over-flight of storms.

PROJECT HAILSWATH: Project Hailswath, the multi-agency, NSF-sponsored program for hailstorm modification, was noted in the introductory paragraphs of this section. From the AFCRL viewpoint, hailstorm modification is simply a special case falling into its more general and continuous program dealing with the precipitation structure of convective clouds.

Beginning in the summer of 1966, AFCRL meteorologists used the C-130 aircraft to make a number of preliminary observations of hailstorms occurring in the Upper Great Plains region.



These two photographs show a thin section of the same hailstone photographed in unpolarized light (A) and polarized light (B). Such analysis tells much about the growth history of the hailstone.

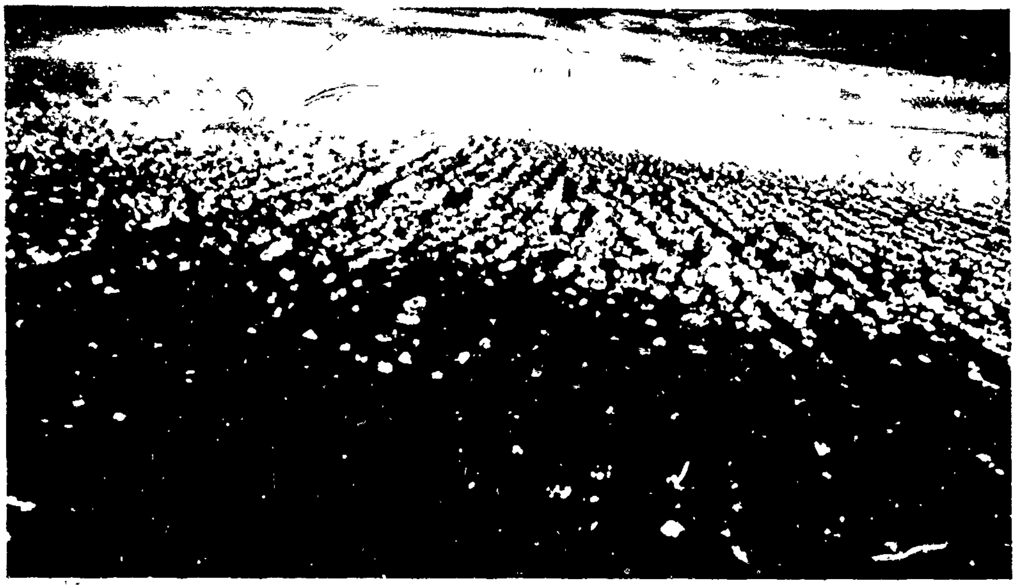


First, AFCRL wanted to see if hailstorms were sufficiently isolated, simple and small to permit meaningful measurements. Two-thirds of the hailstorms were found amenable to such measurements. Next, in conjunction with other Project Hailswath participants, AFCRL made a number of measurements of temperature, humidity, wind, liquid-water content, turbulence and precipitation particles in hail-producing convective clouds.

The Project has already resulted in a number of interesting observations. From 20,000 to 30,000 feet, it was seen that the storms were often part of a line of convective cells. A more remote view of the patterning of these cells, AFCRL suggested, might provide clues to incipient hailstorm formation, and such a view might best be obtained from weather satellites. Many of the hailstorms were seen to grow and develop by incorporating smaller adjacent cumulus elements. This observation suggests that the growth pattern could be disrupted by seeding the small "feeder" elements.

CUMULUS CLOUD POPULATIONS: In contrast to the destructive convective systems discussed above, most cumulus cloud populations are benign. Typically, they form in the mid-morning, achieve maximum size in the mid-afternoon, and dissipate before sunset. Time-lapse photography has become a basic technique for studying this growth and dissipation. Such films of the busy, rapid movement of cumulus elements across the sky and their boiling, convoluting formation and disappearance are endlessly fascinating. Many requests for AFCRL time-lapse film footage have come from commercial and educational film producers and TV stations for general public showing.

AFCRL is interested in the study of cumulus cloud populations and the patterns these populations assume because they are visible manifestations of general convective phenomena. The patterning that these cumulus elements assume in time and space is a function of several factors, the most important of these being temperature, winds and dewpoints. If the interrelationships of these factors can be clearly identified, models of cumulus cloud formation and growth can be developed. And it may be possible, on the basis of cloud populations observed from weather satellites,



At certain times of the day and under proper conditions, small fluffy cumulus clouds form in rows stretching for many miles. AFCRL has studied the meteorological conditions which give rise to this curious cloud pattern.

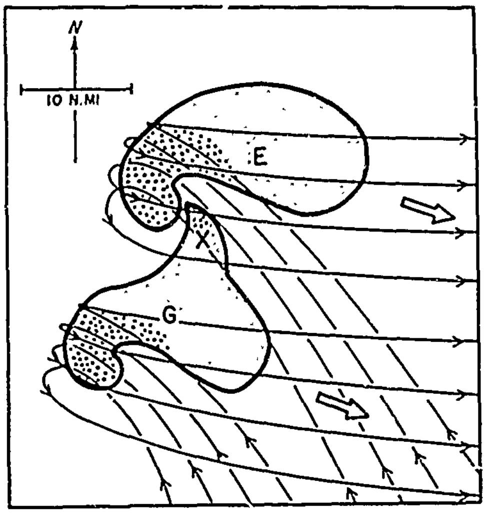
to specify the conditions existing in the first 10,000 feet of the atmosphere.

For a number of years a group of AFCRL meteorologists has carried out summer expeditions to Florida to observe all aspects of weather formation over the peninsula and the adjacent Atlantic, Caribbean, and the Gulf of Mexico regions.

Typical of the studies of cloud populations was one concerned with cloud rows. Cloud rows consist of a geometrical arrangement of small fluffy cumulus clouds sometimes stretching across the entire Florida peninsula. They begin to form along the coastline at about 8:30 a.m., after the earth has absorbed heat from the sun. However, they are observed most frequently and cover the greatest area during the early morning hours and in the middle to late afternoon. They are relatively infrequent during midday, often disappearing only to reappear again in the afternoon after the time of maximum surface temperatures. By 5:00 p.m., the geometric row pattern has broken up.

Each cumulus element may be only a few hundred feet from base to top. Sometimes the base is at an altitude of only about 500 feet, and rarely is the base higher than about 3000 feet. The rows themselves are usually closely spaced at the time of initiation—about 1000 to 1500 feet separation. The distance between rows may increase to 10,000 to 15,000 feet in the late afternoon. Frequently, the geometrically spaced rows will break up, losing their precise patterning to assume a random arrangement. When this happens, the breakup occurs more or less simultaneously over large regions of the peninsula encompassing both coastal and interior regions. But just as often as not, given the same apparent meteorological conditions, the cumulus elements do not arrange themselves in a pattern at all.

From all this it would seem a relatively simple matter to isolate those factors which give rise to cloud rows and



This diagram looks down upon two adjacent thunderheads moving in an ESE direction. Winds approach the cloud at low levels and leave at high levels going in the opposite direction.

those that do not. It would further seem that winds would be the controlling factor. The AFCRL study was largely concentrated on the wind profiles and wind shears that existed during patternform and non-patternform conditions.

What were the findings? First of all, cloud rows are most likely to form when winds are in excess of ten knots, and the rows tend to be parallel to the direction of the wind. More precisely, they tend to be oriented about three degrees to the left of the surface wind and about 15 degrees to the left of the wind at the cloud base level. But this is only a general characteristic– not a consistently uniform one. Cloud rows were sometimes observed with surface winds of less than five knots and at all angles to wind direction.

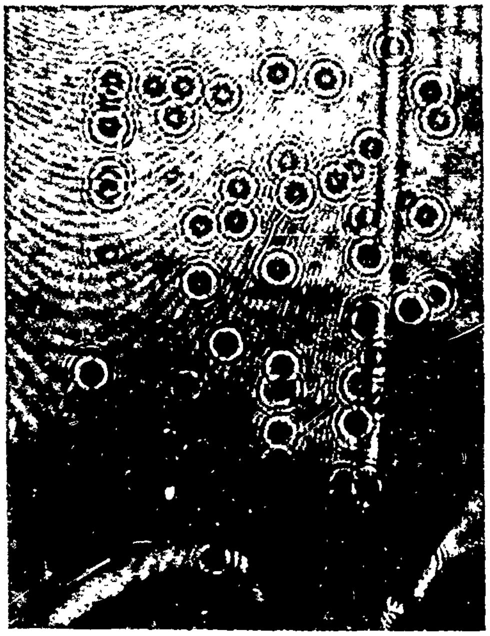
The lack of consistent relationships points up the complexity of even seemingly simple convective systems. In future investigations of these and other convective cloud patterns, AFCRL will attempt to study the details of the wind and the thermal structure of the lower atmosphere, the persistence characteristics of the clouds, and the mechanics of the clustering together of the clouds into various types of group structures.

WARM FOG RESEARCH: The cloud systems considered earlier were all convective systems. Here, stratus clouds will be considered. Whether these clouds occur at ground level in the form of fog or at higher altitudes, they have the same structure. From the standpoint of modification, which is the ultimate goal of this research, warm fog and cold fog present the researcher with two different problems. The warm fog modification problem is far less amenable to solution than the cold fog problem.

In 1964 and 1965 the AFCRL warm fog research program was centered at a site at Otis AFB on Cape Cod where during the summer months warm fog frequently occurs. In this program, nicknamed Project Cat Feet, the emphasis was on learning more about the physical, optical, electrical and hydrodynamic properties.

Much of AFCRL's work on the warm fog problem has gone into the design and evaluation of instruments to probe and learn more about fog itself. Notably lacking are instruments to determine fog droplet size and, in particular, instruments to measure droplet sizes in the 1-5 micron range. Many instruments are presently used by AFCRL to measure fog parameters—transmissometers, capillary collectors, a thermal gradient diffusion chamber, and a laser disdrometer, in which holography is used for measuring size and distribution of droplets within a given volume.

The National Science Foundation asked AFCRL during the period to develop a national plan for a multiagency program aimed at uncovering techniques for warm fog dissipation. The plan has



A hologram such as this, when reconstructed, provides a 3-D view of fog droplets in a volume of space. The technique is used to study the size distribution of fog droplets.

been prepared and submitted to the National Science Foundation.

COLD FOG RESEARCH: Cold fog dissipation techniques have reached a point of operational suitability testing. AFCRL has demonstrated in numerous tests conducted over the past several years that supercooled fog and clouds—where liquid droplets are below freezing temperatures—can be dissipated by dry ice seeding.

In the winter of 1966–67 various tests of the AFCRL technique were conducted by the Air Weather Service at seven different Air Force bases extending from Alaska to Germany. In one instance, at Griffiss AFB, Rome, N. Y., the technique was pressed into operational service when dry ice was used to clear a hole above a fog-obscured runway to permit a disabled B-52 to land.

While earlier feasibility testing consisted of dropping dry ice pellets from aircraft, attention has recently turned to the use of balloons to carry the dry ice aloft. Free flight balloons and tethered balloons have been used.

ATMOSPHERIC DYNAMICS AND BOUNDARY LAYER PHENOMENA

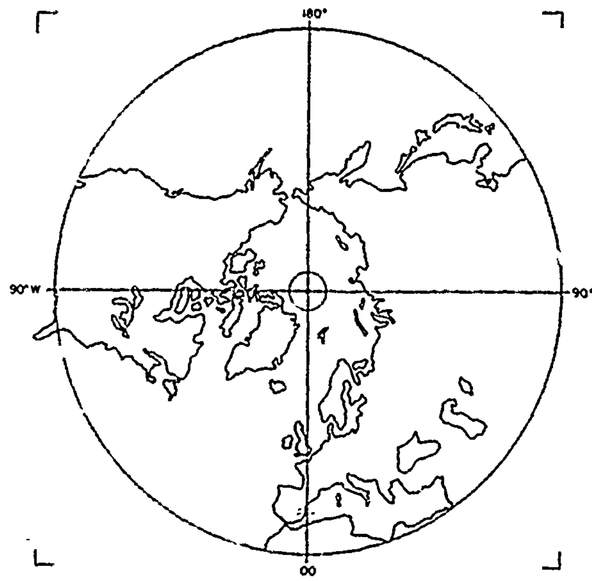
This section will deal with the turbulence, the eddies, the huge vortices, the oscillations, and the general instabilities which manifest themselves as weather and climate. The scale of this research extends in some cases to the circulations over half a hemisphere; in other cases, it is confined to areas of a square mile within which a diversity of instrumentation is set up to obtain extremely fine-grain descriptions of wind fields, moisture, and temperatures.

The cause and effect relationships among the constantly varying, interacting factors are inordinately complex. Numerical models offer the best means for coping with the dynamic physical processes of the atmosphere, processes that often cannot be investigated by other means. Phenomena of great complexity can be replicated numerically and the effects of each parameter of a system studied quantitatively.

Computer modeling techniques have gained a powerful role in general meteorological investigations. Generally such models consist of a closed system of differential equations which describe the physically relevant atmospheric parameters—wind, temperature, density, moisture and so on. Since such systems are fundamentally nonlinear, they must be solved numerically by high-speed computers in an iterative fashion. This is done by first expressing the equation in finite-difference form. The validity of a mathematical model depends, therefore,

both on the physics incorporated in the system of differential equations and on the accuracy of the numerical method being used to solve the finite-difference equations. The validity is tested, depending on the nature of the experiment, either by comparing the computed weather to the observed weather or by comparing the computed parameters to a set of controlled parameters.

Because so much of the Meteorology Laboratory's program in atmospheric dynamics involves computer modeling, there is implicitly a heavy mathematical and theoretical cast to the research. One study involving computer modeling is discussed immediately below.



AFCRL has studied the contributions of auroral heating to the atmosphere by means of numerical models. This is one in a series of computer generated plots showing the dynamic expansion of heat produced by the aurora.

AURORA AND CIRCULATIONS: The earth's weather is primarily sustained by normal solar heating and internal atmospheric processes. If a precise model of atmospheric circulations is to be developed, the effects of various contributions to the dynamic processes which ultimately result in the earth's weather must be known. One minor contributor to these processes is auroral activity.

Auroral activity can affect wind circulations at the earth's surface. This is the implication of an AFCRL numerical model study concerned with the effects of upper atmospheric heating processes on wind circulations in the lower atmosphere. Contributions of heat by the solar corpuscular radiation which produces the aurora, however, are very small relative to other atmospheric heating mechanisms—absorption of visible light by the earth's surface and the lower atmosphere; absorption in the upper stratosphere of ultraviolet radiation by ozone; and absorption, also by ozone, in the lower stratosphere of infrared radiation from the earth. Nevertheless, corpuscular radiation is a significant heat contributor at the roughly 100 km altitude where auroras occur.

The AFCRL computer model of auroral contributions to wind circulations has been solved for two different sets of meteorological records, one for a given date and time in January, the other for April. These records consisted of surface temperatures and the 500 mb (roughly 25,000 feet) pressure field that existed at the onset of an actual large geomagnetic disturbance. With these data as the starting point, the AFCRL investigations introduced into each of the two real situations a mathematically simulated auroral storm of moderate intensity corresponding to those which actually occurred on the January and April dates. The computer then carried out numerical integrations for each of the situations for periods of thirty days in thirty-minute steps. For comparison

purposes, integrations were performed on the same date without auroral heating.

The heating and no-heating integrations developed in a similar fashion during the first two days, during which time they each resembled the real weather development. After two days, significant differences began to develop. The difference between the heating and no-heating cases reached a maximum around the seventh and eighth days and again during a period around the end of the second week. Although neither the heating nor the no-heating forecast fields could be considered good forecasts of the actual temperature and pressure fields after the first few days, the auroral heating cases more closely resembled the observed fields both in January and April.

In summary, the modeling experiments uncovered evidence of a small but noticeable difference in the average circulation that develops between situations in which a small amount of heat is added in an auroral ring and in cases in which no heat is added. Furthermore, the computations confirmed the results of earlier empirical studies which showed the existence of such an effect.

RESEARCH ON NUMERICAL MODELS: The study of auroral contributions to atmospheric circulations is but one phenomenon investigated by numerical models. Much research is done on the general technique of modeling *per se*. One such study involves finite-difference analogues for numerical integration, where the primary difficulty to be solved is that of conserving both momentum and energy.

AFCRL has developed a method, based on a scheme by others (Lax-Wendroff), in which a time step is calculated which conserves both momentum and energy for one complete integrating cycle. Then a new time step is determined for the next cycle and so on. This method depends upon the solution of a 5th degree polynomial in the time interval. There is no guarantee that the method is practical, since there may be occasions when the real roots of the polynomial are unacceptable. Such situations would occur if the real roots were all negative or too large.

The method has been programmed for a simple one-dimensional test system. Starting with a given set of conditions, it was determined that a three-hour time step would conserve both the total energy and momentum. This solution then provided the initial set of conditions for the subsequent processing cycle. In one study, results were obtained for 1000 consecutive time steps and in each of these both the energy and momentum were conserved. To this basic program was later added a term for frictional dissipation. This system is capable of conserving the total kinetic energy by allowing both the coefficient of friction and the time step to vary.

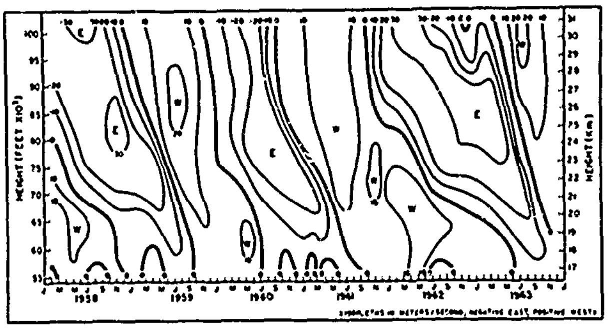
MODEL FOR STRATOSPHERIC WINDS: A numerical model was developed to help explain why the winds in the stratosphere reverse directions every year and how these reversals relate to a two-year pattern of temperature change in the stratosphere. The principal mechanism tested was the postulate that the two-year cycle results from time and space variations in the lag between the heating of the top of the ozone layer by short solar radiation and heating of the bottom of the ozone layer by long wave radiation from the ocean surface.

Eight pressure (altitude) levels were programmed in the non-linear systems of equations. The spacing of the eight pressure levels was highly variable. At

upper levels, where high resolution was required, the vertical pressure interval was small—0 to 2 mb. The bottom layer, visualized as relatively inert, had a large spacing, 1000 to 500 mb.

What this numerical model must do, essentially, is deal with a natural process that occurs over a period of two years. Thus the model design was of necessity greatly simplified. The model accommodates the Reynolds stress terms which are important in this problem since these terms are involved in the large north-south momentum transports that take place. The heating function specified equals zero when integrated over a whole cycle and over the whole volume so that there is no net change of internal energy. Even with simplifications, a greal deal of computational time is involved in the solution. The first integrations were carried out to 45,000 ten-minute time steps—equivalent to almost three years in the model. The motion, starting at rest, gradually increased as the heating function established temperature gradients. Subsequently, a pronounced annual oscillation became established but no two-year oscillation was evident. Recent experiments with certain changes in the modeling conditions—but still with only an annual forcing function—are producing a large variation on the order of one and one-half to two years.

THE HURRICANE MODEL: Of the several numerical models of atmospheric dynamic processes under study, the model that has been given most intensive and complete treatment is a model designed to investigate the conditions under which hurricane-like disturbances will form. The AFCRL model is capable of predicting the motion and subsequent development of a hurricane-like disturbance from initially unperturbed conditions.



Stratospheric winds near the equator change directions about every 26 months. This chart illustrates this oscillating equatorial wind cycle over a six-year period.

During the reporting period, the investigation reached a milestone as an extensive report on the AFCRL study, which began in 1960, was submitted for publication under the AFCRL in-house report series. The principal findings of this study are:

1) The strength (and probably orientation) of the temperature field is one of the most important factors in determining whether or not a large amplitude easterly wave will develop into a hurricane.

2) The single most important dynamic effect is that due to horizontal advection of temperature by the divergent part of the wind.

3) The release of latent heat by the mesoscale motions is not important for the initial intensification of the easterly wave into a hurricane. However, in this model there was no source of moisture except by means of advection through the boundaries, which eventually weakened. If another moisture source is allowed, due to evaporation and turbulent transfer from the sea surface, it is conceivable that the latent heat effects on the mesoscale may be more far-reaching. However, the calculations do show that even in the early stages when there

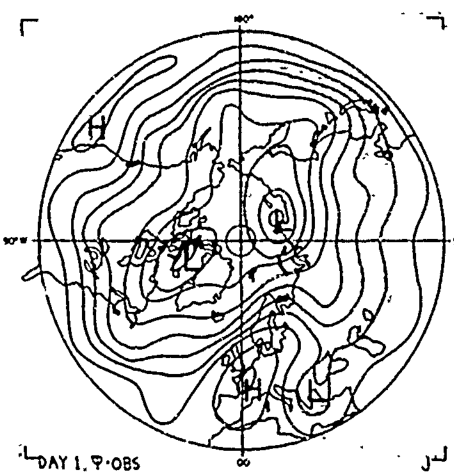
is an abundant supply of moisture there is no significant difference between the date of development and the intensity of the storm when compared with the corresponding no-heating case.

4) The type of frictional force included in the model accelerates development in regions where development would have taken place without friction. It is conceivable, however, that a different formulation of the frictional force could alter this result.

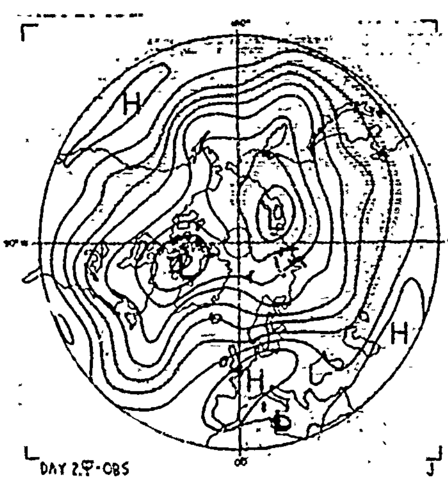
5) The combination of friction and mesoscale latent heat release may be important for the maintenance of the storm in the later stages.

NUMERICAL WEATHER FORECASTING: Making weather forecasts by numerical models is a major goal. In another AFCRL model, the method involves solution of numerical equations on a grid of 400 km. Results from forecasts within this grid are used as the boundary conditions of a more dense but smaller-sized grid network placed within the original one. Successively smaller grids may be introduced so that the final grid-point spacing is as small as desired. With this model 24- to 72-hour predictions for a particular case were made with satisfactory results.

Other mathematical studies are concerned with the prediction of cumulus-type activity, including thunderstorms, and with assessment of the effect of such activity on larger scales of motions.



Numerical weather forecasting is a major research goal. In these two charts, a computer starting with an initial condition (above) plots the evolution of major weather systems, arriving at the condition shown below 24 hours later.



CYCLONIC AND ANTICYCLONIC SYSTEMS: Superimposed on the general west-to-east atmospheric circulation are cyclonic and anticyclonic systems, or vortices. On weather maps they are seen simply as high- and low-pressure centers. Clouds are associated with cyclonic systems; in anticyclonic systems there is an absence of clouds. A satellite photograph taken from the earth, such as those taken by the ATS synchronous satellite, would show at any given time several cyclonic systems over the visible disc of the earth. Some of the largest and most severe of these cyclonic systems are hurricanes and typhoons. Most, however, are simple quasi-circular wind systems with diameters of a few hundred to a thousand miles. AFCRL's study of these systems grew out of an

interest in their relationships to the general circulation and in their seasonal variations. Also of interest is how the systems are sustained over a period of time in the presence of strong frictional dissipation forces. From such studies, it may be possible to refine day-to-day weather predictions.

These cyclonic and anticyclonic systems can be studied quite simply by plotting the pressure centers that appear—or have appeared—on weather maps. In the AFCRL study, a two-year daily record of cyclonic and anticyclonic systems occurring over the Northern Hemisphere was analyzed. The study was undertaken to see if the gross circulation and mechanics of the earth's atmosphere could be deduced by measuring the daily displacements of the systems. Both the cyclonic and the anticyclonic systems have an average longitudinal motion of about 27 degrees during their usual lifetime of about five earth rotations—but there are wide variations between systems. The cyclones in general move toward the poles while the anticyclones move toward the equator. The pattern is not consistent, however. Some cyclones move toward the equator. It was found that such cyclones have a significantly slower eastward motion than those moving in the normal poleward direction. The longitudinal motions of both types are inversely proportional to their size. In the middle and high latitudes the poleward motion of cyclones is directly proportional to cyclone size.

AFCRL has postulated that the formation and the motions of these systems are governed by Rossby waves. Rossby waves are believed to be the momentum sources of the jet stream. Viewed from above, Rossby waves appear as sawtooth-shaped patterns which transfer angular momentum from one region of a rotating body to another region. The Rossby waves themselves are believed to be the result of the earth's rotation and the temperature difference between the equator and pole.

PROJECT STORMY SPRING: The foregoing discussion was concerned with a statistical analysis of many cyclonic systems. Under Project Stormy Spring, AFCRL set out to define the detailed anatomy of individual cyclonic systems.

The study took place in southern New England and southeastern New York state. Within this area—40,000 square miles—AFCRL with assistance from the Air Weather Service, the Weather Bureau, the Navy and the Coast Guard brought to bear an extensive array of observational instrumentation including AFCRL's C-130 and U-2 aircraft and its weather radars. Special mesoscale surface and rawinsonde networks were also established. Intensive observations were made during five storms for periods of 20 to 48 hours between 15 March and 30 April, 1965.

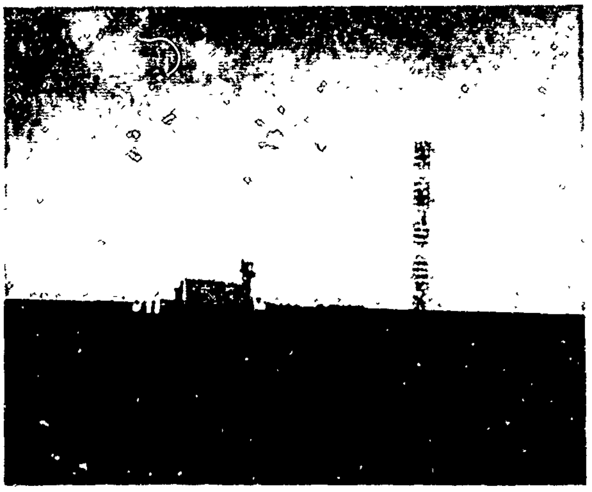
These observations were designed to learn more about such phenomena as cloud and precipitation bands and their relation to the mesoscale wind and temperature fields, zones of extreme wind shear and probable turbulence, and the ageostropic nature of mesoscale circulation systems.

Although the observational phase of Project Stormy Spring took place during the previous reporting period, data analysis took place largely in the present period. Of the five storms observed in the spring of 1965, the moderately intense occlusion of 14-15 April came under the most intensive study. The examination of mesoscale temporal and spatial changes in precipitation, wind and temperature throughout the troposphere and lower stratosphere has revealed remarkable, but by no means

simple, atmospheric structures and processes.

About 80 percent of the precipitation from the storm of 14–15 April 1965 occurred after passage of the "pre-frontal surge" of cold, dry air aloft. This surge is actually the leading edge of the cold air at 500 mb which has overrun the warm air at low levels and created potential instability as much as ten hours prior to the passage of the synoptic-scale surface occlusion. The large scale ascent triggers this instability in the form of bands of convective cells. Such bands are a common feature of radar cyclone models and can be seen imbedded within the large scale frontal cloud bands in satellite pictures.

Mid-troposphere waves in the thermal and wind fields were discovered which had wavelengths on the order of 300 km but the waves in the two fields had no consistent relation to each other as they passed through the Stormy Spring network. Four types of extreme wind shear zones were found at altitude levels from the boundary layer near the earth to the stratosphere. A low-level jet wind occurred about 250 miles ahead of the surface pressure trough which produced turbulence and 42 mph winds at 1 km altitude while relatively light winds with little shear existed above 3 km.



On a broad, flat field in Kansas, AFCRL conducts a program in micrometeorology—the study of winds, temperatures, moisture, and so on, within a space of a few square miles.

Laboratory scientists have prepared a number of papers on various aspects of the project, only a few of which have been noted here. An overall report on Project Stormy Spring will be published in 1968.

ATMOSPHERIC BOUNDARY LAYER: The atmospheric boundary layer refers to the first 5000 feet or so above the surface of the earth. Boundary layer studies are concerned with how the earth, its surface roughness, its evaporating moisture, and its temperature absorption and reemission properties modify wind flow and contribute to the dynamic properties of the atmosphere. Two of AFCRL's several programs on boundary layer phenomena are noted in the following paragraphs.

The first of these is the Haven Acres program, discussed in the previous *Report on Research* under the designation "Windy Acres". This program is being conducted at a site established in 1965 on a broad, flat, obstruction-free wheatfield in Kansas. The program is designed to measure a variety of meteorological parameters within a limited space of about one square mile and within the first 100 feet of the atmosphere. The Laboratory is interested in obtaining data on the profiles of wind, temperature, moisture, and the vertical turbulent transport of momentum, heat, and water vapor.

The Haven Acres program uses a computer-controlled data acquisition system for rapid handling and processing of data from various micrometeorological sensors at the field site. This

system, called The Mobile Micrometeorological Observation System (MMOS), was developed by AFCRL scientists. Experimental field programs in the past had been hampered by the inability to handle large amounts of data in the field. But this difficulty has been overcome through the use of the MMOS which controls automatically all the operations required in an experiment.

In each experiment, the system scans and reads the outputs from a pre-determined number of sensors (for wind, temperature, and so on) on a 100-foot tower, edits and processes the data, and records the results on magnetic tape. A printed real-time display of some of the important statistical parameters is also provided to keep the operator up to date on the state of the atmosphere. The system is capable of sampling sensor signals at rates up to 50 times a second, which is faster than the normal requirements for turbulence analysis.

Another boundary layer investigation concerns the formation and dissipation of low-level jet winds. These jets occur at night and are most prevalent in the mid- and southwestern United States. They are of particular interest because wind velocities can reach up to 75 mph in a relatively shallow layer anywhere between 1000 and 2000 ft., unknown to observers at the ground or at higher altitudes.

AFCRL scientists have been analyzing data from measurements made in 1963 with sonic anemometers operating at heights of 150, 450, 750, and 1050 ft. on a television tower at Cedar Hill, Texas. These anemometers measured the vertical component of the wind, which is a very good indicator of turbulent mixing. The data confirm the role played by turbulence during various stages of the jet's development. There is evidence of periodic breakdowns of inversion layers below the jet maximum and strong vertical mixing following the breakdowns. The data also show the existence of slow vertical undulations at the level of the jet maximum.

Arranged at intervals along a 100-foot tower at the Kansas micrometeorological observational site are sensors for measuring winds and temperatures.

SATELLITE METEOROLOGY

Effective application of meteorological satellites depends foremost on the development of techniques for extracting meaningful quantitative information from the wealth of photographs and infrared data transmitted from these satellites. This is a problem that has occupied AFCRL's attention since the launch of the first TIROS satellite in 1960.

During the reporting period, the Laboratory undertook a new and substantial program related to tropical meteorology, a program designed to improve the precision of forecasts in a region of the

world now of obvious concern. The Laboratory's tropical meteorology studies, concentrated in Southeast Asia, emphasize the use of satellite data in forecasting techniques.

Increasingly, the Laboratory has been called upon by the Air Force and the DoD to provide guidance and consultation in matters pertaining to the development and application of satellites to general military operations. For example, pictures portraying rare cloud lines, sometimes hundreds of miles long over the oceans, were brought in by the DoD for interpretation. It developed that these were most likely the product of ocean-going vessels whose exhaust nuclei enhanced cloud development in an otherwise near nuclei-free atmosphere.

AUTOMATIC PICTURE TRANSMISSION: Satellites such as the TIROS VIII, NIMBUS I, NIMBUS II, ESSA-2 and ESSA-4 were designed to make direct transmissions to ground stations all over the world where relatively inexpensive Automatic Picture Transmission (APT) equipment is installed. AFCRL operates two such equipments, one for research at its main laboratories in Bedford, the other at the Chico, California, balloon launch facility. The latter is used operationally by the Balloon Launch Group (see Chapter V) for monitoring weather systems approaching the California coast from the Pacific.

The AFCRL-developed Muirhead equipment used in connection with AFCRL's APT equipment produces satellite photos with greater contrast and clarity.

The APT research equipment, installed in 1964, is used primarily to evaluate and improve APT performance. AFCRL modifications have increased the capability of the system to provide high quality photographs. This work led to AFCRL's providing technical personnel to check out operational equipment in Saigon and Kunia, Hawaii, and to incorporate AFCRL-developed modifications.

One such modification was to use the Muirhead photofacsimile machine which provides high quality 8x8 pictures. This recorder has a compensation panel which permits adjusting the grey scale of the picture. Advantage was taken of this feature (the most valuable characteristic of the recorder) to compensate for the gamma of the photographic paper and the camera characteristics to produce pictures with much better information in the black portion of the scale. A technique for achieving a linear scale in density as a function of log of signal voltage (which is called a linear grey scale) was also developed for the system.

During this period, an AFCRL scientist made the discovery that height information to an accuracy within plus or minus two km is possible by using adjacent APT pictures as stereo pairs in the region of overlap. This discovery represents a useful advance in satellite photo interpretation.

INFRARED STUDIES: Infrared sensors aboard aircraft and satellites looking down on cloud systems from above

can provide information on cloud height, cloud thickness and on atmospheric water vapor that eludes other sensors.

One IR study is concerned with the interpretation of NIMBUS II infrared photographs. These pictures were centered on the water vapor channel (6.4 to 6.9 microns) of the five channel Medium Resolution Infrared Radiometer. Prominent features in the pictures were bands of dry air of the order of 200 miles wide and as long as 1500 miles or more. Sometimes they appear as spirals associated with cyclonic water vapor vortices, which appear as lighter areas.

The NIMBUS pictures analyzed also showed that water vapor vortices occur twice as often as cloud vortices, that the water vapor vortices are accompanied by 200-mb troughs, and that a 200-mb jet stream is located from 6 to 12 degrees latitude south of the center of all but one of the water vapor vortices observed.

The most prominent features in the water vapor channel appear in mid-latitudes. However, intense convective systems were also detected in the tropics. A greater spatial resolution or instrument sensitivity could possibly resolve upper-level tropical cyclones, a pre-stage of some tropical storms.

A second program consists of observations from a U-2 aircraft in the 8–12 micron "atmospheric window" and in the 14–16 micron carbon dioxide absorption band. In spite of instrumentation problems, such as reference cavity drift and stabilization, some reliable data have been collected. The data collected are of sufficient accuracy to deduce the radiational characteristics of various cloud regimes. A survey has been completed on data collected over and in cirrus clouds associated with jet streams.

Based on some 30 flights with different radiometers, certain radiational characteristics are deduced. It was found, for example, that the black body assumption is in error with respect to the cirrus cloud regimes. Only ten percent of the data analyzed show black body characteristics, while about 75 percent exhibit an emission coefficient of 0.5. The effect of this characteristic could result in error between 10,000 to 20,000 feet in estimating cloud top heights. Other radiational characteristics of cirrus regimes show that they are inhomogeneous, that they radiate in a sine pattern, and that the emitted radiation is integrated over a much larger thickness of the cloud than previously believed.

TROPICAL METEOROLOGY: AFCRL has undertaken a study to correlate and interpret Southeast Asia weather data gathered from many sources. One of

A three-dimensional view of the cloud systems photographed by weather satellites is possible with this simple optical system.

these sources is weather satellite information recorded with the APT equipment in Saigon. In addition to routine satellite pictures, magnetic tapes from the Saigon APT equipment are sent to AFCRL on a regular basis for study. Another data source are CPS-9 radar reports in the Saigon area. From these data, the Laboratory has developed a method of predicting the probable occurrence of shower activity in the Saigon area, given an initial set of meteorological conditions. One observation made during the course of this particular study is that on days when the radar index rises to unusually high values in the afternoon and evening, the morning satellite picture usually shows a distinctive east-west band of clouds, south of the Indo-China peninsula, extending for thousands of miles. This band is not present on the "quieter" days. Although this condition lasts for several days, suggesting it is a result of at least synoptic-scale processes, it was not reflected on the weather maps.

Another study involved high-resolution infrared data acquired during the 1966 summer monsoon season. The data show a diversity of IR patterns associated with the monsoon from day to day. Several unique patterns occur repeatedly. Extremes of high and low radiation values are particularly meaningful. High values are indicative of conditions with no middle and high clouds. Low radiation values are indicative of dense high clouds. Comparisons of IR data with radar and rainfall data were made. Results indicate that low radiation values are closely related to convective storms.

The Southeast Asia studies show that the conditions which give rise to the patterns of weather in this area are quite different from those governing the more familiar patterns over temperate regions.

STRATOSPHERIC PROCESSES AND EFFECTS

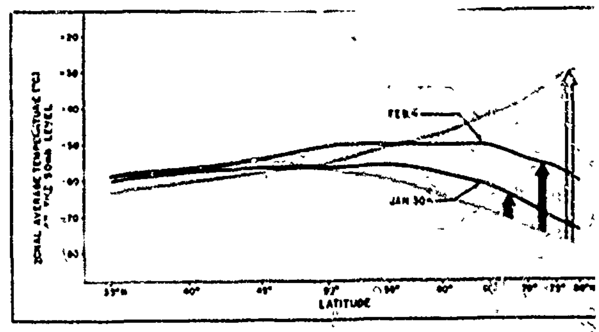
Wind and temperature patterns between about 15 and 50 km—the stratosphere—bear little resemblance to those of the lower 15 km of the atmosphere. Yet strong dynamical linkages exist between the high- and low-level flow regimes. Long range weather prediction must take into account these incompletely understood coupling mechanisms.

Knowledge of stratospheric processes can never be complete without subsidiary knowledge of the distribution of ozone in time and space. Ozone is a primary regulator of the radiative thermal budget of the stratosphere—the amount of heat received from the sun against that which is re-radiated back into space. Ozone is of further interest because it provides a tracer for the study of the mixing and transport mechanisms that take place between the stratosphere and the upper troposphere. The sometimes turbulent mixing at the stratosphere-troposphere interface results in the clear air turbulence (CAT) which affects aircraft operations. A special program is formulated around the CAT problem.

EXPLOSIVE WARMING OF THE STRATOSPHERE: AFCRL's study of a phenomenon known as explosive warming of the stratosphere has led to a complete study of the dynamics and thermodynamics of the wintertime stratosphere, including all forms of energy transformation and exchange.

Sudden warming of the stratosphere was first noted in 1952 by a German meteorologist who observed a rapid increase in stratosphere temperatures over Berlin. This observation was significant because it had been assumed that the only changes in the stratosphere are the slow, large-scale seasonal

shifts in temperature and circulation that repeat themselves year after year. Since 1952, explosive warmings have been observed to occur on the average of about once every three years. During an explosive warming, the temperature in large regions of the stratosphere generally increases from around -60 degrees to -30 degrees C in less than a week. [illegible] warmings have occurred most often in mid-January. Five cases have already been observed in 1952, 1957, 1958, 1963 and 1965. A study of data from January 1958 shows that this warming was caused by a large-scale disturbance propagating upward from the troposphere across the stratosphere-troposphere boundary. This conclusion was unexpected because meteorologists had always assumed that troposphere energy systems were not transported into the stratosphere. The thermal structure of the stratosphere, they believed, would result in a rapid damping of such disturbances. While this damping does occur with the disturbances of the size of travelling cyclones and anticyclones, the AFCRL study shows the much larger scale disturbances can and do propagate to very great heights during the period from October to April. The interpretation made by AFCRL is that when a sudden development of a planetary wave occurs during the winter season in the troposphere, a massive amount of mechanical energy is propagated upwards where it produces regions of anomalously high temperature and radiation of energy out to space. A follow-up study of large-scale disturbances during the winters December 1962–February 1963 and December 1963 –February 1964 confirms the importance of these large-scale disturbances.



SUDDEN WARMING

During the winter, the stratosphere sometimes undergoes a sudden, explosive warming. This feature of the stratosphere was discovered only in recent years. The influence of these explosive warmings on the earth's weather has not yet been fully determined.

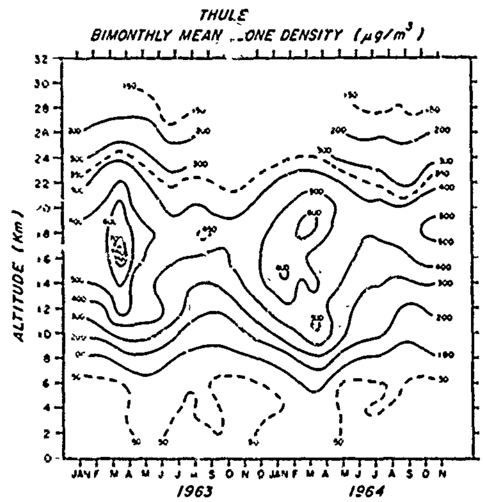
STRATOSPHERIC WINDS: Stratospheric winds, like tropospheric winds, vary with season, latitude and altitude. During the period, the Laboratory completed a study of diurnal wind variations in the stratosphere to see if a relationship could be found between the diurnal wind patterns between altitudes of 27 to 36 km and the wind patterns that should result from the daily heating and cooling of the ozone layer. It was assumed that since the diurnal temperature variation is simple and symmetric, the resultant wind pattern should also be simple and symmetric. The study was based on data from consecutive daily observations—two measurements daily —made during the summer months over a region stretching from western Europe through North America to eastern Asia and at the 15, 10, 7 and 5 mb levels. Analysis showed that horizontal and vertical wind patterns were far more complex than the simple pattern predicted from radiative effects. The patterns also suggested that large-scale topographic features such as continents, oceans and mountain ranges can influence stratosphere wind patterns.

Although clear relationships between diurnal heating and winds were not observed, the data did uncover a number of systematic dynamic variations of the stratosphere. In particular, a planetary wave disturbance was detected travelling westward at 30 degrees of longitude per day, producing prominent variations in the prevailing easterly winds. This disturbance was observed from altitudes of 25 km to above 50 km. The cause of the disturbance is unknown but it is probably forced by disturbances in the troposphere which are hidden by the many small-scale disturbances.

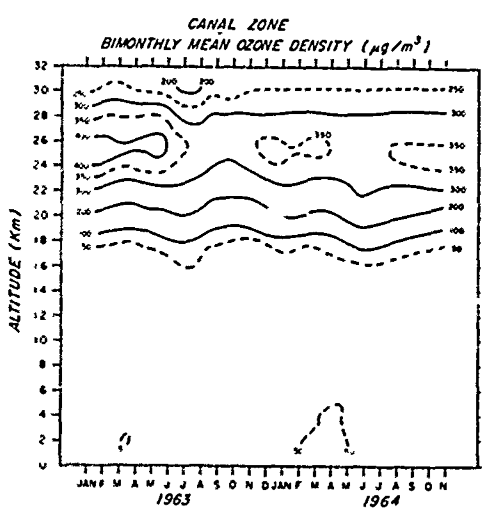
OZONE MEASUREMENTS: In any set of equations dealing with the atmospheric heat budget, ozone absorption in the stratosphere is a fundamental factor. For example, at about 30 km (10 mb) ozone absorption of direct solar energy contributes more than 80 percent to the atmosphere's heat with another 10 percent of the heating resulting from ozone absorption of reflected radiation from the earth and clouds. At about 20 km (50 mb), these figures are 70 and 15 percent, respectively.

The importance of ozone in meteorological processes led AFCRL, in 1963, to establish an extensive ozone data-collecting network covering half the globe. The network consists of 11 stations extending from Alaska and Greenland in the Arctic to Grand Turk Island and the Canal Zone in the equatorial regions. Once a week (every Wednesday) since then, balloons carrying ozone measuring instruments are released simultaneously from each of these stations. Special two-week periods are sometimes scheduled for more intensive daily observations. Instruments were designed to collect information on stratospheric ozone up to 30 km.

AFCRL has applied the wealth of ozone data collected by the network to problems of the stratospheric heat balance. One result of the study is a greatly simplified model of the radiative balance in the stratosphere, a model which permits the prediction of stratospheric temperatures, at least in the warmer half of the year, with remarkable accuracy.



In these two charts the mean ozone densities for Thule, Greenland (above), and the Canal Zone are compared. Relatively heavier ozone concentrations at lower altitudes are found in the northern region.

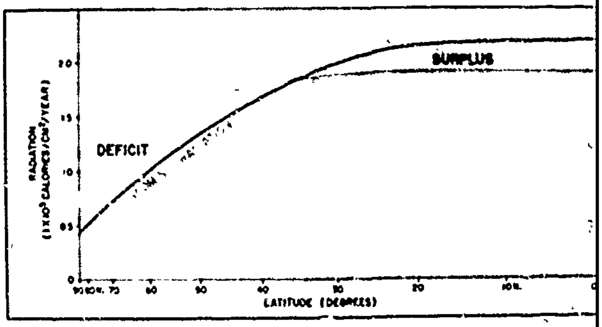


Three factors are involved in stratospheric temperature changes—solar heating, transport of heat by atmospheric circulations, and radiative (infrared) cooling. Data on ozone concentrations gathered by the AFCRL network provide a basis for calculating total solar heating with an accuracy not previously possible. The net effect of the two other factors—transport and radiative cooling—can be evaluated simply by subtracting the calculated solar heating rate of ozone from the observed temperature change. This net is called the "balance requirements."

When this is done, one would expect to find an erratic relationship between the balance requirements and the observed mean monthly temperature. This would be expected for two reasons. First, stratosphere temperature should fluctuate due to atmospheric transport processes; second, heat should be lost to space and exchanged with other levels by infrared emission and absorption in some non-linear relationship to temperature. For the warmer months, May through October, this is not the case. Instead the balance requirements are a linear function of temperature.

This discovery has several interesting implications. One is that during the warm months the stratosphere must be in radiative equilibrium on the average. Transport processes noted above resulting in explosive stratosphere warming in the winter contribute negligibly to the change of summertime monthly mean temperature. This is, of course, the classical view of the stratosphere, but in recent years it has been increasingly challenged.

Another implication is that the net infrared transfer of heat in the stratosphere can be calculated by an enormously simplified procedure. The new AFCRL procedure can account for the observed mean temperature at all latitudes in the lower stratosphere with a standard error of only about 2 degrees C.



RADIATION BUDGET

Basic to the understanding of the earth's weather is the earth's radiation budget—the amount of heat received from the sun as against heat reradiated into space. This diagram shows radiation received and lost as a function of latitude.

CLEAR AIR TURBULENCE: In an earlier section of this chapter, CAT research was discussed in the context of ground-based radar detection. Here, the study concentrates on a more complete description of the mesoscale atmospheric structure that gives rise to turbulence. These investigations, based on detailed aircraft measurements of wind and temperature, are intended to provide the knowledge required for improved prediction of CAT and for the development of airborne CAT sensors. Because CAT is so strongly associated with the mixing of stratosphere and troposphere air, AFCRL has suggested that airborne ozone measurements could also be used for diagnosis of meteorological events associated with the establishment, maintenance, and decay of the turbulent areas.

AFCRL's U-2 aircraft, used in many Laboratory investigations, was withdrawn from AFCRL during 1966 for

other Air Force purposes. The loss was most severely felt by those scientists at AFCRL working on problems of clear air turbulence. This instrumented aircraft was the primary data collector under the CAT program.

Analyses of the U-2 data revealed several interesting features regarding jet stream turbulence. In connection with the polar and mid-latitude jet streams, CAT appeared to be a more likely occurrence above the level of maximum wind (LMW) rather than below, and it was a distinct minimum at maximum winds. The CAT found above the LMW was in the so-called "tropopause break" region. The CAT in the "break" region appeared to be sandwiched between very stable layers above and below.

In the "break" region, interleafing of stratospheric and tropospheric air streams can take place, and, indeed, the ozone variations suggested that such a condition is frequently established. The relevance of interleafing is that it is likely related to a differential advection process which in turn can readily alter the vertical wind shear and thermal stability. Turbulent areas sometimes extended 300 miles across and 7000 to 8000 feet vertically. However, the vertical extent was generally less than 2000 feet. The Richardson Number criterion appeared to be a fairly good discriminator between CAT and no CAT, and it gave a correct score of 80 percent on 439 cases which included 149 CAT cases. A surprising point was that the Richardson Number could not discriminate light CAT from the more intense types.

METEOR TRAIL ANALYSIS: There are six radars in the free world designed to derive information on upper atmospheric winds and densities from the ionized trails of meteors. Meteorites enter the atmosphere so frequently that almost continuous data on upper atmosphere winds can be provided by the radar. One of these radars was installed at AFCRL in June, 1964. These radars are capable of continuously monitoring a segment of the sky and automatically recording wind data in the region between 80 to 120 km where meteors are vaporized by atmospheric friction. Under computer control, the AFCRL meteor trail set has attained unattended operation for periods of more than one week.

The AFCRL radar is experimental, with current emphasis being on the development of automatic data reduction capability. Modifications are in progress to give more detailed azimuth information, and to improve previous bias in the system against low radial wind speeds.

This radar has high potential for use in Air Force missile and satellite launch

Wind speed and direction at high altitudes can be measured continuously by observing the effect of winds on ionized trails of meteors. This Yagi array is used to measure the paths of meteor trails.

operations where continuous knowledge of upper wind structure is important. Because of the high radio noise level at Hanscom Field in Bedford, Mass., where the set was initially installed, and because interference is particularly strong at the operating frequency of 36.8 MHz, the decision was made to transfer the radar to the University of New Hampshire for further development and test. The set was transferred to this new site in May, 1967.

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VII Solid State Sciences Laboratory

The Solid State Sciences Laboratory is concerned with electromagnetic materials, the phenomena they exhibit, and the exploitation of these phenomena to accomplish useful functions of particular value to military technology. The program of the Laboratory encompasses material purification, growth and synthesis of semiconductor, magnetic and optical crystals, the evaluation of the material characteristics, and the fabrication of prototype devices. Giving cohesion to these efforts is a small theoretical program on the basic structure of matter.

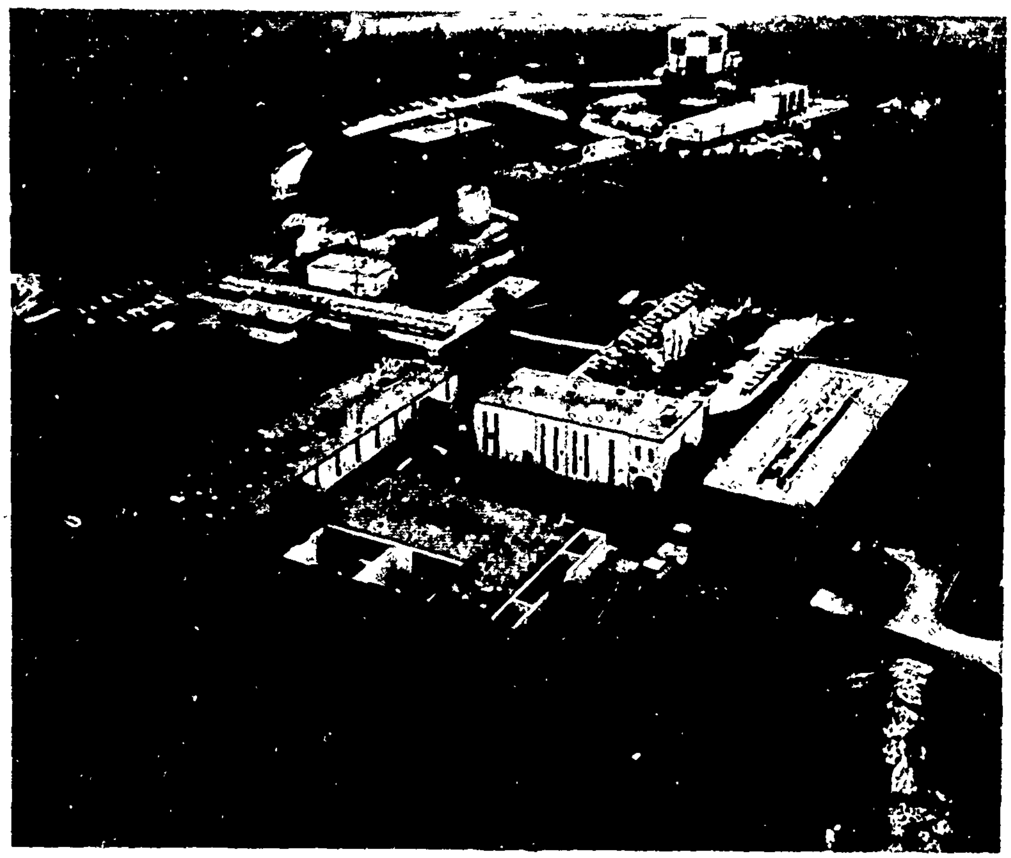
Most operational ambitions of the Air Force are limited by the performance of available materials. The Air Force's detection, surveillance, computation and communication capabilities are all materials limited. More specifically, the Air Force requires electronic devices with improved radiation and temperature resistance, greater sensitivity, higher power operation, improved speed, enhanced reliability and decreased size and weight. The goal of this Laboratory's efforts is to extend the present limits of electronic material performance.

The facilities for conducting this research are among the most complete in the country. There are few optical, semiconductor, or magnetic crystals of any type that the Laboratory does not have the capability of producing. The Laboratory also has facilities for research in single crystal thin film technology. Coupled closely with crystal growth facilities are a host of analytical techniques for determining crystalline structure,

purity and electromagnetic phenomena and properties exhibited by the crystals. Fabrication facilities and a range of analytical instrumentation are also available for experimental device development. For the study of the effects of ionizing radiation on materials and devices, AFCRL operates a 1 MeV Dynamitron, a 3 MeV Van de Graaff generator, and a nominal 12 MeV linear accelerator.

MATERIAL SYNTHESIS AND ANALYSIS

This section covers some of the techniques used by the Solid State Sciences Laboratory for synthesizing and analyzing materials. The Laboratory has prepared hundreds of different, potentially useful materials and has evaluated their properties. Most of these materials are prepared in single crystal form. Among the general classes of materials that have been of most interest to the Laboratory are the aluminum oxides, of which ruby is the best known, silicon carbide, and the lithium germanates. The Laboratory has pioneered in the last of these materials and they appear to be exceedingly promising for lasers and as a luminescent medium for electronic displays.



AFCRL's solid state research is conducted in this complex of buildings at L. G. Hanscom Field, Bedford, Mass.

Depending on the particular electronic material, the properties of interest are its transport, magnetic and optical characteristics. The transport characteristic of most interest is conductivity (or conversely, resistivity). Temperature, pressure and stoichiometry all have a strong influence on resistivity. In a particular crystal, the addition of a minute trace of a dopant material—only one part in a billion—may increase the resistivity of the crystal a thousandfold. A 1 percent addition of a material may reduce resistivity by ten orders of magnitude or more. It is apparent then that the growth of a crystal with predetermined characteristics requires the utmost precision and control.

The optical characteristic of a material takes one into quantum mechanics and excitation mechanisms. The concern is with energy levels in which an atom absorbs a photon and is excited from its ground state to a higher energy state.

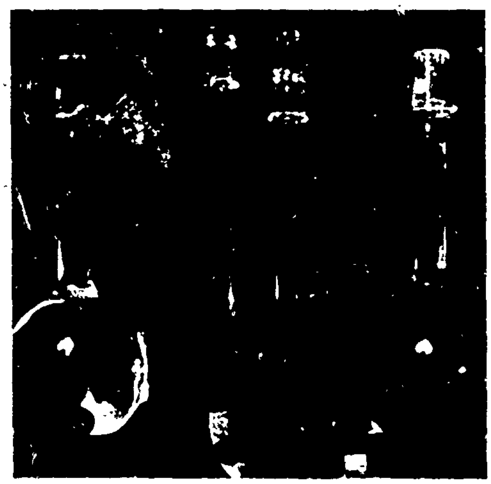
The materials program of the Laboratory has five basic parts: a fundamental understanding of crystal purification and growth, synthesis and preparation of materials, the determination of the properties of these materials, the measurement and analysis of the phenomena exhibited by such materials, and the application of these results for device purposes. Recent progress made in these areas is discussed under various headings that follow.

GEL GROWTH: Most techniques for growing electronically active single crystals require high temperatures. But when crystals are grown from vapor, melt or solution, inherent limitations develop at high temperatures. For example, crystalline imperfections are more apt to occur due to the disruption of the lattice by thermal vibration; the danger of contamination from impurities is higher due to their increased solubility with temperature, and point imperfections and lattice strains are generally introduced into the crystal during cooling to room temperature.

In a silica gel solution, crystals as long as one inch can be grown.

One growth method under intensive study which avoids many of these high temperature limitations is growth by gel. This method has been employed for obtaining crystals which cannot be satisfactorily grown by other methods. The gel provides a three-dimensional porous network which permits reagents to diffuse, prevents turbulence and yields mechanically to the growing crystal.

The growth of crystals in porous media is encountered in nature in the growth of ice crystals in soil and in the growth of gypsum in clay. Gel investigations date back more than 60 years, although little of a scientific nature was achieved until very recently. The emphasis at AFCRL is on the physics and



Containers used for growing crystals assume many geometries. In this container cuprous chloride, an electro-optic crystal, is grown.

chemistry of gel growth per se, and secondarily on growing selected materials for electronic devices.

One material studied was calcium tartrate tetrahydrate to assess its potential as a matrix into which active dopants could be introduced for application in solid state devices. Large neodymium-doped crystals were obtained (up to one inch on edge) by reacting a calcium chloride solution containing a small amount of neodymium acetate with a silica gel. The gel is prepared by mixing controlled amounts of sodium metasilicate and d-tartaric acid. This is then allowed to set in a 500 cc cylinder until it is semi-solid. Calcium chloride is then added to the cylinder where it remains above the gel.

The crystals, after growing for six to eight weeks, take on a form which to all outward appearance seems to have been cut and polished. They are of the orthorhombic system and occur either in bipyrimidal or trapezohedral habit. The undoped crystals are colorless and clear, while the neodymium doped specimens adopt a purple hue. Crystallinity was verified by x-ray Laue measurements. Attempts to lase the doped specimens have to date (July 1967) proved unrewarding, possibly due to the molecular structure or to interference of the water molecules contained in the crystals.

Laser beam modulation is essential to optical communications. But high modulation frequencies must be used. One method of modulation is to use the Pockels effect, a linear electro-optic effect which consists of a change in crystal refractive index as a function of applied electric field. Materials manifesting this effect and most commonly in use today include ADP and KDP (ammonium and potassium dihydrogen phosphate). Limitations in these crystals resulted in a laboratory study into other materials with improved properties.

One electro-optic material studied and successfully grown by the gel method is cuprous chloride. CuCl melts at 422 degrees C and crystallizes in a hexagonal phase, but at 407 degrees C converts to the desired zinc-blende form. In conversion, the crystal is badly strained and because of its 400 degrees C maximum annealing temperature, these strains cannot be effectively annealed out. Thus, the melt grown methods result in highly strained materials, regardless of crystal size. Using gel techniques, the Laboratory was able to grow perfectly formed (tetrahedral) crystals up to a quarter inch on edge at room temperatures—more than 350 degrees below the point of transformation. The characteristics of these materials and their use as a laser modulator are under study.

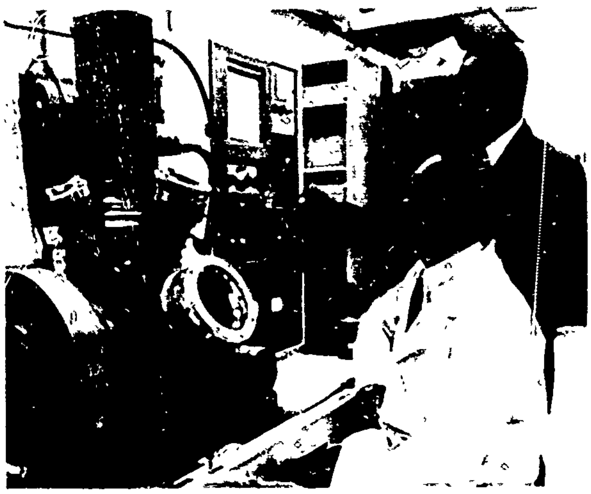
GROWTH OF GERMANATE CRYSTALS: During the reporting period, a variety of germanate compounds was studied to

assess their value as luminescent or laser materials.

These materials, both crystalline and glass, were prepared by the Czochralski method and by slow cooling. The widely-used Czochralski method is a process in which a relatively cool single crystal "seed" is lowered into a melt held exactly at the melting temperature. The seed is then withdrawn slowly so that the melt at the growth interface is frozen and pulled from the solution. By proper control of temperature and pulling rate, it is possible to produce single crystal cylinders up to several inches in diameter. In recent years, this method has been used in pulling crystals from fluxed solutions, as well as from the pure melt. By using fluxed solutions, a major limitation of the Czochralski method may be overcome, namely the fact that the crucible melts before the crystal material does.

With the fluxed solution technique, large chromium doped lithium germanate single crystals, which possess reproducible luminescent properties, have been grown. The unusual and varied luminescence displayed by this compound led to an extended investigation which consisted of the substitution of other transition ions for the chromium ion. The luminescence of these germanates has been observed over a range of temperatures and under different kinds of activation.

Additional studies are underway to gain some understanding of the basic mechanisms underlying the luminescent, lasing and other properties of these germanate systems. Application of these materials in detector, display, laser and logic devices will be investigated. Evaluation of these crystals is discussed below.



The Czochralski process in which the crystal is drawn slowly from molten material is a basic method for growing rubies and germanate crystals.

EVALUATION LITHIUM GERMANATE: The Laboratory investigated the potential of the lithium germanate crystal and sodium germanate glass systems as possible optical laser materials. The chemistry, structure, dopants and impurity levels of the crystals were studied by classical chemical methods, gamma ray spectroscopy, mass spectographic analysis, emission spectroscopy, electron microprobe, and flame photometry. As a result of these measurements, the crystal was determined to have the chemical formula $Li_2Ge_7O_{15}$ with various transition metal and rare earth ion dopings. The lattice was found to possess orthorhombic symmetry. From x-ray diffraction patterns the lattice parameters were calculated as $a = 7.388$, $b = 9.712$, and $c = 16.738$ angstroms. Crystals of lithium germanate were also analyzed by electron probes for the chromium variation. It was found that the distribution was constant at all positions.

Fluorescent emission of orthorhombic lithium germanate crystals doped with varying amounts of chromium were measured between 6500 and 9000 angstroms. These measurements indicated

the presence of two sets of no-phonon "R" lines accompanied by a group of lower energy vibronic satellites. The R-line fluorescence for a lithium germanate sample with a chromium concentration of 0.16 percent by weight at room and liquid nitrogen temperatures was measured. The broad peaks observed at 300 degrees K are composite R_1, R'_1, R_2 and R'_2 lines which are unresolved. But at 80 degrees K, the R_1 peaks are clearly resolved at 6961 angstroms and at 6954 angstroms, while the two additional R_2 peaks are in the vicinity of 6930 angstroms. At liquid helium temperature, the R_1 and R'_1 peaks are slightly narrower, while the R_2 and R'_2 peak intensities are too low to be observed. Although the peak heights increase between 300 and 77 degrees K, the strength in the R_2 lines decreases relative to that of the R_1 lines as the temperature is lowered. The R-line behavior of this sample at 300 degrees K and 77 degrees K was compared with that of a red ruby of nearly the same chromium concentration measured under the same spectral resolution conditions. At both temperatures, the R-lines for lithium germanate are found at longer wavelengths than ruby and have a wider separation. The sharp lines observed at low temperature indicate that this material is a good laser possibility at these temperatures.

Two views of a ruby crystal grown by the flame-fusion process are shown here. The crystal was grown with crystal axis parallel to the growth axis. The hexagonal configuration seen in the lower photo indicates good control of growth parameters. The crystal is about one inch in diameter.

The absorption spectra of chromium-doped lithium germanate and of ruby are very similar, with two major bands and with lines in roughly the same positions. The spectra differ, however, in the number of lines comparable to the ruby's R-, S- and B-lines. The data were measured from 3200 angstroms to 21,000 angstroms. No detectable absorption was noted above the R-lines at 7000 angstroms. The two major bands in the spectrum of lithium germanate occur at about 17,000 cm^{-1} and 23,500 cm^{-1}, and are referred to as the U and Y bands, corresponding to the nomenclature for the ruby spectrum. Measurements indicate that the Y band is consistently the

more intense in all three polarizations, and varies in peak intensity by a factor of two. The peak intensity of the U band, on the other hand, varies by 12 percent. In the ruby spectrum, the Y band also varies with polarization by a factor of two, but the U band varies by a factor of three.

A preliminary evaluation of the Cr^{+3} doped lithium germanate system indicates that, given a good quality crystal, lasing action should occur at liquid nitrogen temperatures, but not at room temperature.

SILICON CARBIDE: In 1959, AFCRL sponsored an international conference on silicon carbide. The proceedings of this conference have become the most frequently referenced document in the literature of this material. Since that time, AFCRL has acted as a center of information on all aspects of silicon carbide semiconductors.

Silicon carbide is difficult to prepare in electronically useful form, and cannot easily be fabricated in devices. Thus, the material is unlikely to see use in integrated circuits. The continued interest in silicon carbide arises from its unique combination of physical, chemical, optical, thermal and transport properties which make it a potentially very important semiconductor material for high temperature and high radiation flux environments. It can also operate at high input powers.

Unfortunately, the very properties that make silicon carbide technically attractive, also make it very difficult to grow as reproducible single crystals of acceptable size and purity. Moreover, silicon carbide comes in many crystallographic polytypes. There is only one cubic form but there are many closely related hexagonal and rhombohedral polytypes. These non-cubic forms are usually grown from the vapor state at temperatures of about 2400 degrees C. In this review, discussion will be confined to research on the cubic diamond zinc blende (3C) form.

Because silicon carbide has no melting point at normal pressures, it cannot be grown by normal melt techniques. The cubic form can, however, be grown in silicon rich melts in the temperature range of about 1500 to 1800 degrees C. Because the solubility of carbon at these temperatures is only about one tenth of one percent, only small crystals of platelet, rod and dendrite forms can be grown. In fact, in order to grow SiC crystals at all, it is necessary to establish a temperature gradient such that more carbon dissolves at the hotter part of the crucible (usually near the top of the melt) and is precipitated on the bottom part of the crucible.

By taking extreme care of purity conditions, and precisely adjusting temperature gradients, the Laboratory has grown single crystals of several millimeters in length and width and about one-tenth millimeter in thickness. These crystals are large enough and are of sufficient quality to encourage the Laboratory to believe that the growth of beta silicon carbide is not limited by fundamental considerations.

Laboratory scientists have carried out more than 100 such melt experiments using a variety of conditions of thermal gradient, temperature, length of runs and additives in the melt to either increase the carbon solubility or to inhibit spurious nucleation. The AFCRL technique is potentially suitable for supplying crystals for device manufacture.

To grow larger silicon carbide boules, it will be necessary to increase the carbon solution to several percent. The Laboratory is investigating several possible ways to do this. One is a search

Silicon carbide, although a difficult crystal to synthesize and to fabricate into devices, has high resistance to temperature damage.

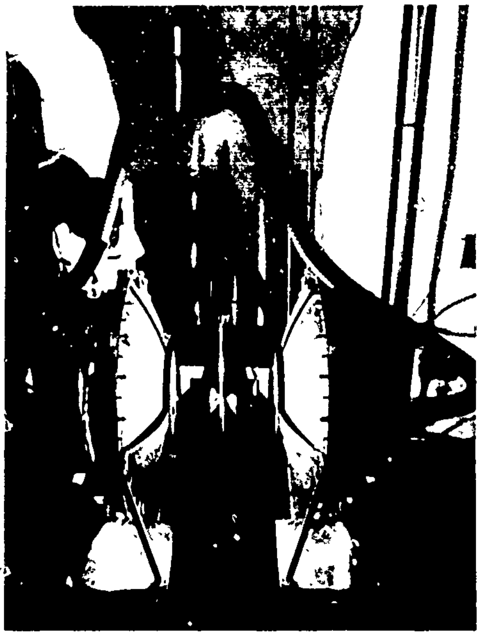
for an additive which would increase carbon solubility in the melt.

Another approach is to grow beta silicon carbide by the hydrogen reduction of organic intermediates such as methyltrichlorosilane (CH_3SiCl_3). The Laboratory has investigated a number of such materials within the temperature range of 1000 degrees to 1500 degrees C by deposition onto a carbon substrate. In this way, the Laboratory has grown very thin (one micron) single crystals of beta silicon carbide onto alpha and beta silicon carbide and silicon substrates. With an appropriate substrate (other than silicon carbide) for depositing single crystals, the requirements for large boules of beta silicon carbide could be reached. For this purpose, a series of metal silicides, particularly chrome disilicide and cobalt monosilicide, have been grown in large boule form. They should provide a combination of properties more suitable than silicon for epitaxial growth. In particular, they should provide improved lattice match, improved temperature coefficients and some mutual solubility between substrate and deposit. The present stage of this work is to adjust the deposition conditions for optimal growth within the temperature capabilities of the substrates.

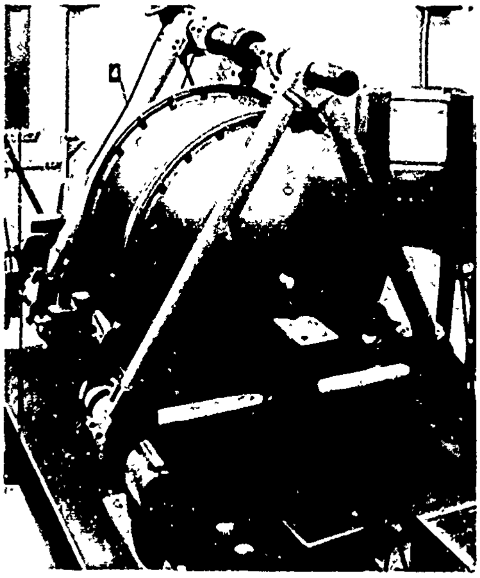
In the course of this epitaxial work, the Laboratory grew crystals of Wurtzite (2H) modification of silicon carbide. Laboratory scientists were able to explain this modification in terms of a vapor-liquid-solid growth mechanism originating in impurities in the substrate. By eliminating the impurities, the 2H crystals did not form. Then by purposely introducing selected impurities, it was possible to grow either 2H or 3C (cubic) crystals at will. Ignorance of the true nature of 2H growth has caused confusion in the literature since their discovery in 1959. Their growth, intermingled with cubic growth at 1500 degrees C, was often interpreted as evidence that the cubic form was not a thermodynamically stable form, even at low temperatures.

THERMAL IMAGING FURNACE: A basic crystal growth problem is that of crystal contamination during growing—contamination resulting either from atmospheric particles and gas or from the combustion residue of the heat source. Thermal imaging overcomes this problem by transporting the radiant energy by optical means to a volume of space physically removed from the source. The radiant energy is focused at a particular point by means of a parabolic mirror.

AFCRL conceived and designed the first thermal image furnace in 1956. The furnace is known by the appropriately descriptive term, the clam-shell furnace. It consists of two parabolic mirrors facing each other and very closely spaced so that the focal points are actually outside the mirrors. By cutting a small aperture in the center of each of the two mirrors, it is possible to place the heat source at one aperture and to create



With this thermal imaging furnace, radiant energy is focused at the growth area by means of parabolic mirrors. Two pairs of mirrors are used in the AFCRL furnace.



a virtual image of the heat source at the other aperture. Now if two of these clam-shell furnaces were brought together, two heat sources could be used with the heat from both focused at a common point near the two inside apertures.

AFCRL had A. D. Little build such a furnace under contract. The A. D. Little double clam-shell furnace is powered by two ten kw Xenon arc lamps, each of whose energy is focused on a common work zone where melts can be obtained for crystal growth. Following a period of many years, during which little further work was done on the clam-shell furnace, the work was again activated during the reporting period. The clam-shell furnace concept was advanced to the point where it promises to see widespread use among crystallographers for crystal growth.

There are several advantages to the thermal image crystal growth method. First, the growth region is isolated from the contaminating influences of the heat source. Second, the growth region can be enclosed in an optically transparent, hermetically sealed housing which permits virtually full control of the environment. Materials can be grown in a vacuum or under pressure, and can be protected from atmospheric oxidation and contamination. With this basic furnace, different mechanisms can be used to allow for Verneuil, Czochralski or float zone methods of growth. AFCRL operates two such clam-shell furnaces—one with ten kw lamps, the other with five kw lamps.

Temperatures up to 3000 degrees C can be produced in the growth zones. For effective operation, the radiant energy must be focused upon the material with a minimum loss of energy density arriving at the target. Using the five kw furnace, AFCRL has melted quarter

inch rods of alumina (mp 2050 degrees C). A melt was also obtained on the end of a rod of stabilized zirconia (mp 2750 degrees C).

FLAME FUSION TECHNIQUES: Much Laboratory effort has been spent to optimize the flame fusion method (Verneuil) of crystal growth, a method that dates back 60 years. Optimization means precise control of crystal growth parameters.

As part of this program a new, low turbulence oxyhydrogen burner was designed in conjunction with American Science & Engineering, Inc., and put into operation. The burner is a three-tube postmix type, with a design which avoids the sharp turbulent mixing zones of the usual tri-cone burner. Also, a water cooling device was developed for use as an attachment when growing crystals of materials with melting points above 2200 degrees C. Crystals of rutile, nickel oxide, sapphire, ruby and spinel with diameters in excess of 22 mm have been grown.

For well over half a century the Verneuil technique has been used to grow single crystals. Powder drops through a hydrogen-oxygen flame onto the growing crystal boule.

Another new furnace is one designed for precise control of boule position, rotation and retraction rate. It also includes improved control of flame shape and gas flow past the crystal. This improved furnace has made possible the growth of ruby with zero degree orientation and hexagonal cross section, a morphology indicative of low radial gradients and crystal perfection.

Another furnace which shows a great deal of promise for precise control was developed in conjunction with the University of Michigan. This is a fully automatic Verneuil machine which monitors the plane of crystallization continuously and controls the retraction rate to maintain a constant crystal position in the flame. The machine, when fully operative, will also be programmed through the entire growth cycle to produce more nearly identical growth conditions from run-to-run, leading to an improvement in the reproducibility of crystal boules.

As a separate general study, the Laboratory is compiling quantitative data which will relate all relevant growth parameters to the resulting crystal characteristics and performance.

STUDIES OF DEGENERATE GERMANIUM: The energy band structure and electronic properties of degenerate germanium have been investigated using a unique method of tunnel transport spectroscopy which was developed by the Laboratory. The data obtained in these studies gave new insight into the fundamental differences in the properties of ordered and disordered materials.

Device technology usually requires heavily doped materials which have great lattice disorder. Precise theoretical descriptions of such materials are lacking because of variables of unknown relative magnitude. To be considered are several host lattice atomic potentials, free electron corrections, impurity and defect potentials and the random distribution of atom types on host lattice sites. As a result several models have been developed to explain the energy band structure of disordered semiconductors, none of which share substantial agreement. AFCRL has developed a method which allows the mapping of the energy band structure of a degenerate material by spectral analysis of current voltage characteristics of tunnel diodes measured at 4.2 degrees K. The details of the analysis and the experimental arrangement have been reported in the literature. The key results obtained are:

1) Extensive doping (up to 5×10^{19} As atoms cm^{-3}) of germanium resulted in no gross changes of the energy band structure. In other words, there were no measurable changes in the relative position in energy or momentum of the two principal minima of the conduction band of Ge.

2) Good agreement was obtained with the semiclassical model for energy band structure in which the band edge is well defined in any microscopic region but varies from point to point as a result of local fluctuation in impurity density.

3) The macroscopic band edge was found to be exponentially distributed.

4) For impurity densities greater than $10^{19} cm^{-3}$ the band edge was found to sharpen with increased doping. This may be indicative of possible inter-impurity ordering or the formation of a partial impurity superlattice.

It should be noted that exponential band edges have also been proposed to explain the spectral shift noted in GaAs laser diodes. The present results indicate that such edges are to be expected in any material where there is considerable interaction between impurities.

Used for metallurgical and epitaxial investigations is this induction heated horizontal furnace.

DIAMOND GLOW CURVES: When ultraviolet energy irradiates certain materials cooled to liquid nitrogen temperatures, these materials emit a thermoluminescent glow as their temperature rises. Thermoluminescent emissions are stronger at certain temperatures and wavelengths than at others. Plots of the emissions as a function of the temperature of the material are known as glow curves. Glow curves are a fairly standard analytical technique.

Glow curves promise to become an important analytical technique for semiconductor materials. To refine the technique and to evolve methods for interpreting the resultant data, the Laboratory studied glow curves on diamond which exists as either a semiconductor (Type II b) or an insulator (Types I and II a).

AFCRL scientists were interested in the defects in diamond, since defects

AFCRL produced its first man-made diamonds in 1958 using this tetrahedral anvil press.

give a material semiconductor properties and serve as traps and electron-hole recombination centers. Thermoluminescence is one of the few methods available which can tell the solid state physicist something of the defect properties and trap depths. Trap depths is another way of describing the energies required to release electrons from traps. The data can also indicate the relative magnitude of the densities of the traps and sometimes their capture cross sections. The kinetics, or types of electron transitions, can often be derived by controlling the experimental parameters. Ultimately, these data may give insights into methods for implanting defects more effectively in a given material, thus creating semiconductors of enhanced performance.

To produce thermoluminescence, a sample at liquid nitrogen temperature is excited with ultraviolet or other types of radiation. This raises electrons to high energy levels where many are caught in traps. Because of reduced thermal vibrations of the lattice at low temperature, many of the electrons remain in the traps until the temperature is raised. When the temperature is raised, thermal agitation releases the electrons from the traps. Electrons are released from the shallowest traps first—then progressively from the deeper ones. Some of the electrons released from the traps undergo radiative transitions as they fall to lower energy levels, thus creating the observed thermoluminescent emissions—which are recorded as glow curves. From the shapes of the peaks in glow curves, a variety of information can be derived.

The shapes of the glow curves vary with experimental conditions, and this provides the basis for data interpretation. In the AFCRL experiments, several experimental parameters were independently varied: 1) rate of increase of sample temperature; 2) UV exposure dose, and 3) elapsed time between exposure and initiation of temperature rise.

By controlling the duration of exposure, it is possible to accentuate the growth of certain individual glow peaks. This is accompanied by simultaneous decrease of other nearby peaks, and appears to be related to retrapping of the electrons. In retrapping, an electron is freed from a shallow trap, only to be recaptured in a nearby, deeper trap. Observation of the retrapping process gives clues to the proximity of defect centers.

CHROMIUM IONS IN RUBY: This study concerns ruby that is heavily doped with chromium ions. The interactions between pairs of some of the chromium ions creates entirely new fluorescent systems in the crystal. This observation has

The Laboratory uses a range of equipments for growing, characterizing and testing crystals. In the upper left is a cold hearth arc melting furnace for preparing refractory metals. In the upper right is an electron beam evaporator for deposition of thin filmed alloys. Photo in lower left shows an electron beam and hollow cathode heated furnace for growing refractory materials by the float zone method. Below right is an ultrasonic bonder for making contacts on silicon carbide semiconductors.

several implications. Although relatively high ion concentrations tend to quench the fluorescence (and thus the laser emission) at normally observed frequencies, such concentrations may result in laser emission at new frequencies. AFCRL has in fact observed laser action at two frequencies in heavily doped ruby due to pair transitions. The pair system in heavily doped ruby is also important in other quantum electronics applications. For example, transitions in the ground state manifold of the pair systems may be useful for masers and quantum counters in the submillimeter range.

Absorption, excitation, continuous fluorescence and pulse fluorescence measurements were made on ruby samples with 0.94 percent and 2.1 percent Cr^{+3} at temperatures from 4.2 degrees K up to 700 degrees K. The widths, positions, intensities and lifetimes of the R and N fluorescence lines were determined at numerous temperatures.

Linewidths were found to be temperature dependent and this dependence was explained in terms of microscopic strains, Raman scattering of phonons by the impurity ions, and direct phonon processes. Lineshifts with temperature were explained on the basis of the absorption and emission of virtual phonons. The temperature dependence of the relative intensity ratios of the no-phonon lines was used to construct energy level diagrams for two pair systems and to assign the lines to specific transitions.

Ratios of the intensities of the R_1, R_2 and N_2 lines to the N_1 line were proportional at high temperatures but not at low temperatures, indicating that energy transfer between single-ion and double-ion systems is temperature and concentration dependent. The results were explained by a theoretical model of phonon assisted energy transfer.

OUTLINE FOR SEMICONDUCTOR RESEARCH: Part of the Laboratory's responsibility is that of maintaining a broad perspective of the entire electronics materials research field and of recommending or supporting research in those areas that might not be adequately supported. It would be well to review the conclusions of a study conducted by the Laboratory on areas where additional semiconductor research is needed.

For lack of new materials, there could be a decline in the not far off future in the availability of new electronic devices. The AFCRL study suggests that so many researchers are now so busily engaged in narrow and isolated aspects of semiconductor applications that insufficient attention is being given to more fundamental research on semiconductor materials.

Among the approaches that researchers might take to redress the imbalance are the following: Investigate correlations among chemical bond phenomena at one deeper level of comprehension; support basic theoretical efforts such as band theory; in III-V compounds, emphasize wider gap materials, particularly gallium phosphide and aluminum phosphide; in group IV, emphasize beta silicon carbide; in group II-VI, clarify the lattice defect compensation problem and attempt to eliminate, control or circumvent it, and investigate new methods of more rapidly, accurately and economically evaluating chemical and structural perfection of semiconducting crystals.

SENSORS, SOURCES AND DEVISES

This section is concerned with the physics of devices, device concepts and device techniques. Where the previous discussion covered research into the properties

of materials, this section discusses applications of the phenomena exhibited by these materials to perform useful functions. As such, the research to be discussed here represents, in part, an extension of the work discussed previously.

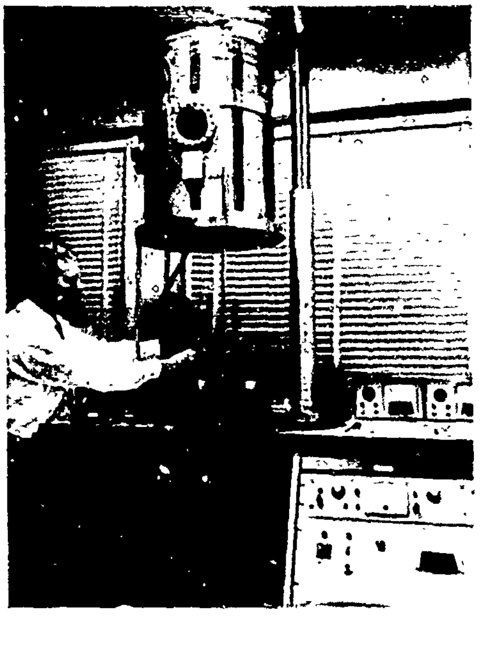
During the reporting period, in response to Vietnam requirements for new technical capabilities, the Laboratory began a new program concerned with improved infrared sources and sensors. The program is both theoretical and experimental. Infrared devices are, of course, of prime military importance, not only in relation to Southeast Asia problems but for a wide spectrum of Air Force and other military applications. This new effort may take the Laboratory well into the region of prototype fabrication.

The modest effort on lasers within the Laboratory is oriented toward applications where sensors and sources must have compatible characteristics. Current emphasis is on semiconductor lasers, and more specifically on gallium arsenide lasers. Although, as seen in the foregoing section, the Laboratory has the capability for growing and evaluating laser crystals with great precision by a variety of methods, such crystals are not used by the Laboratory for developing laser devices. They are, however, made available to laser researchers in AFCRL's Optical Physics Laboratory (Chapter X) where AFCRL's pulsed laser research program is centered.

HIGH SPEED INFRARED SENSORS: In 1966, the Solid State Sciences Laboratory initiated a program in infrared detection processes, devices and device materials. The program was initiated as an exploratory effort and was later expanded upon the recommendations of the Air Force. Emphasis has been on those areas that might offer improvements in Air Force tactical warfare capabilities.

The exact constraints imposed on detectors by low altitude operations of high speed aircraft have not yet been defined. But certain requirements are obvious. These are fast response time, good signal-to-noise ratios, and minimal cooling requirements.

Initial emphasis was on detectors for the one to two micron "night glow" region. Future work will extend to ten to 15 microns. After considering a range of possible directions for the new program, the Laboratory settled on Schottky barrier diodes as potentially the best detectors in the one to two micron region. Schottky junctions are formed between suitable combinations of semiconductors and metals. When these materials come into contact, there is an instantaneous current flow between them



For Schottky junction preparation, this ion-pumped, high-vacuum system is used.

because of their Fermi level difference which results in a potential barrier. (For an n-type semiconductor, a high work function metal is needed so as to deplete mobile charges in the region of the semiconductor nearest to the junction.) The internal barrier height is the difference between the metal work function and the semiconductor electron affinity. Barrier height which controls the magnitude of majority carrier flow is always smaller than the semiconductor band gap. The energy dictates the magnitude of the minority current component. This means that diodes can be designed where majority current flow will predominate. Near ideal majority carrier Schottky junctions have been formed between various combinations of semiconductors and metals, notably n-Si and various high work function metals such as nickel and gold.

Photons with energy greater than the barrier height striking the junction will excite electrons in the metal so that they are able to surmount the barrier. The resulting short circuit or open circuit voltage is the output signal. Thus, this device responds to wavelengths corresponding to energies greater than the barrier height. A weakness in the devices is their low quantum efficiencies—1 to 4 percent at best. But they are extremely fast. They also have the distinct advantage of being able to extend the cut off wavelength of any given semiconductor beyond its intrinsic region depending upon the particular metal used in the barrier.

At present, the in-house program is concentrating on improving the quantum efficiency of hot electron Schottky barriers. The first experimental devices have been fabricated. Preliminary measurements indicate satisfactory photodetection can be achieved. Much work, however, remains to be done before the Schottky can be classed as a competitive, infrared detector.

COLD CATHODES: Research on cold cathodes is concerned with techniques for substituting the hot filament in a conventional cathode ray tube with a cold cathode. Because of the many potential advantages of cold cathodes, laboratories all over the world are working on cold cathodes through a range of approaches. The AFCRL approach is the possible application of the Schottky junction (see item above).

In an ideal n-semiconductor-metal Schottky junction, under forward bias, electrons are transported over the barrier from the semiconductor into the metal. The electrons, thus injected into the metal, have a narrow distribution in energy near an energy above the Fermi level equal to the barrier height. If the film is thinner than the mean free path of these hot electrons, a sizable portion of the hot electrons is ballistically transported across the film without suffering energy loss, and emitted into the vacuum if the metal-vacuum work function is relatively low. Thus, a Schottky barrier with a sufficiently high barrier has the potential of being developed into a cold cathode.

Conventional cathode ray tubes suffer from the shortcomings of the hot filaments, which would be alleviated with the advent of cold cathodes. Cold cathode ray tubes would have several advantages over present tubes. These are longer lifetime, higher resolution and lower noise.

INJECTION LASERS: Injection laser research at AFCRL is primarily concentrated on GaAs lasers and the physics of their operation. Fabrication techniques are studied as well. This research led during the reporting period to the

highest efficiency GaAs laser yet produced.

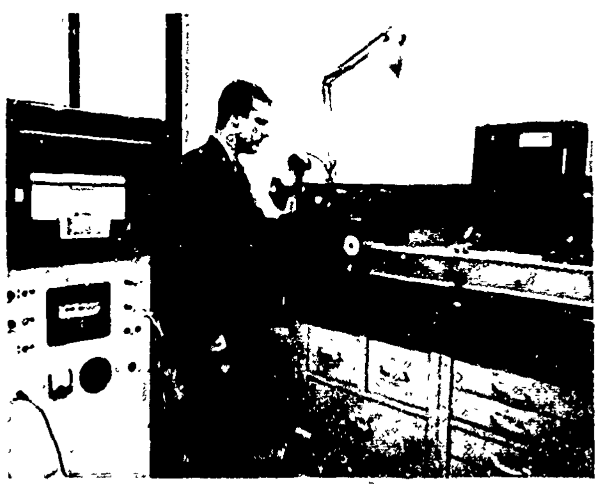
Investigations of the laser cavity led to a description of the mode guiding effects within the laser and an explanation of some of the puzzling fine structure in the laser far field pattern. It turns out that the individual modes within a laser do not travel in straight lines between the Fabry-Perot faces, but follow a dielectric, constrained periodic path. The characteristics of this path may be used to predict some details of the structure of the far field pattern.

Knowledge of cavity characteristics and zinc diffusion parameters was applied in the development of a multiple diffusion process to form high quality laser cavities. The resultant gallium arsenide injection laser had the surprisingly high efficiency of 15 percent and a three watt CW output. This represents a three-fold increase in power and a 100 percent improvement in efficiency over the best previously reported GaAs lasers. Output measurements were made from the front face of the diode at liquid nitrogen temperatures. The CW lasers were fabricated by diffusing zinc into n type ($4x10^{18}$ atoms/cm) GaAs to form a junction five to eight microns deep. After initial diffusion the zinc source was removed and the GaAs was subjected to another diffusion at an elevated temperature of 1000 degrees C for two hours. Since there is no source of zinc present in this second diffusion, the junction moves less than one micron. But without the long second diffusion, the junction will not lase.

Work on $Ga(As_x P_{1-x})$ has led to a method of pumping CdSe. A CdSe platelet is mounted on a Fabry-Perot face of a $Ga(As_x P_{1-x})$ laser and optically pumped by the output of the injection laser. The CdSe lases when the $Ga(As_x P_{1-x})$ reaches threshold. Single mode operation has been achieved. This technique has been extended to Cd(SeS), and this II-VI mixed compound has lased from near the long wavelength limit set by CdSe to the short wavelength limit determined by the direct-indirect transition of $Ga(As_x P_{1-x})$. Cd (SeS) platelets have also been readily lased with a pulsed argon laser.

DAMAGED SURVEY OF PULSED LASERS: A whole new domain of applications awaits the pulsed laser system that can handle high input power without destroying itself. But the rods, mirrors, prisms and lenses of laser systems are all subject to damage when operated at high power. Even when the system is operated at moderate powers over a period of time, breakdown can occur through minor accumulative modifications.

During the period, the Laboratory examined the nature of the damage to laser systems and components. The



AFCRL developed this laser microscope for the analysis of transparent materials such as laser rubies. The microscope is used to evaluate the damage which occurs in crystals after high-powered operation.

AFCRL study is based on the analysis of reports in the literature on the breakdown of laser systems.

In spite of the rather massive amount of laser research going on everywhere, no one has given much attention to a systematic analysis of damage-producing mechanisms. There is no compilation of data on various breakdown mechanisms in order of relative significance. Everyone involved in solid state laser research knows, of course, that the laser rod is a vulnerable component in the laser system and that structural imperfections and impurities influence rod damage. But from the standpoint of designing more damage-free systems this knowledge isn't very useful. Structural imperfections and impurities in the laser rod and in associated glass components occur in a number of forms which are difficult to isolate, identify and count. Progress towards damage-free systems, however, depends upon just that.

Damage to the rods, lenses and prisms of laser systems usually consists of pits on the surfaces and bubbles and fractures that take place internally. The AFCRL study indicates that the power level at which damage occurs depends on the composition of the specimens, the manner in which they were grown and prepared for use and, in crystalline components, on their orientation.

Of the laser damage problems considered, the one to which most attention has been given is: How does energy accumulate to the extent that damage results in laser components? Three primary mechanisms have been proposed:

1) Self-focusing, attributed to the amplitude-phase perturbations of a plane electromagnetic wave in a nonlinear dielectric, creates converging "pipes" in which light and acoustic waves tend to concentrate. Little experimental work has been done on self-focusing in solids, in spite of the common occurrence of filaments of high energy in lasing elements.

2) Stimulated Brillouin scattering provides a means of coupling acoustic and optical waves in a manner resulting in the concentration of acoustic waves. Experimental investigations of this mechanism have been primarily limited to liquids. So far, it has not been directly proved to result in damage in solids.

3) Multiphoton absorption, the successive absorption of two or more quanta of light by the same atom, has been found to occur in ruby. In this material, it could represent a major source of damage, though no direct evidence demonstrating this has been presented. The operation of this mechanism is dependent on the characteristics of the electronic states of the electromagnetically active ion.

A secondary mechanism is microplasma generation. Laser operation requires that a laser rod reach a temperature sufficient to cause at least a small amount of ionization. The ionized material will absorb the laser beam and will become hot enough to damage the material. Although this mechanism has been found to function on the surface, it has not been shown to take place within the body of a specimen.

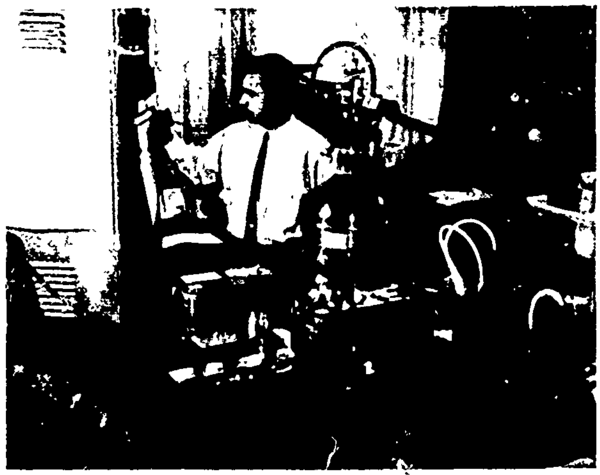
RADIATION EFFECTS RESEARCH

High energy particles in space—cosmic rays, solar protons and the electrons and positive ions in the radiation belts—can all damage, and thus cause malfunctioning of, electronic systems in space vehicles. A nuclear explosion emits a prompt pulse of gamma rays and x-radiation which could affect missile guidance systems. Several satellites have

become inoperative because of radiation damage to electronic components.

The vulnerability of electronic systems to radiation damage underlies AFCRL's research program on radiation effects. From this program, the Laboratory is attempting to define the critical thresholds of radiation damage that particular electronic materials and devices can withstand, and to test new materials and device structures for radiation resistant properties. The ultimate goal of this program is the fabrication of radiation hardened devices.

As was noted in the introduction to this Chapter, the Laboratory operates a number of radiation producing laboratory equipment—a linear accelerator, a Cobalt 60 source, a Van de Graaff generator, and a Dynamitron. The Air Force's entire exploratory development program and the bulk of the basic research program in radiation damage effects to electronic materials and devices have been assigned to the Solid State Sciences Laboratory.



For analysis and characterization of materials, the Laboratory uses spectroscopic instruments of many kinds. Instruments associated with infrared spectroscopy are shown above; below are instruments associated with Mössbauer spectroscopy.

SECONDARY ELECTRON EMISSION: Secondary electron emission from solids exposed to gamma rays and high energy electrons do not cause permanent damage to the material, but nevertheless create disrupting transient effects in electronic systems. When this happens, the missile or vehicle under the control and guidance of these systems may fail in its mission. The magnitude of transient effects from secondary electron emission has been uncertain. An AFCRL study was undertaken to obtain experimental data.

Secondary electron emission can be induced by electron bombardment or by gamma radiation. Quite a bit of data on secondary electron emissions produced by electron bombardment exists in the literature. But for emissions produced by gamma rays, literature data are lacking. A series of experiments was designed to determine whether the data and resultant models of secondary emissions from electron bombardment are applicable to gamma-induced secondary electron emission.

In these experiments, measurements were made of the secondary electron

The 3-MeV Van de Graaff accelerator is the workhorse of much of AFCRL's radiation effects program. Electrons, x-rays, and a host of high energy beams of positive ions are provided by this instrument.

yields from a number of elements—silver, gold, aluminum, platinum, and so on—subjected to Cobalt 60 gamma rays. Measurements were made of emission yield per unit of deposited energy. This affords advantages of mathematical simplicity over measurements of yield per incident photon.

The energy deposited in the test material by gamma radiation is defined by using the material as the inner wall of a cavity chamber. Two methods of determining the deposited energy are possible. The calculation is straightforward if the incident photon flux, its energy spectrum, the true absorption coefficient of the material, and the irradiated area are known. An alternative is to use the emission chamber as an air ionization chamber and to determine the absorbed dose from Bragg-Gray theory. Because this approach does not require accurate knowledge of the photon flux, energy spectrum and so on, it was chosen for the experiments. The experimental configuration employed was that of a multiple parallel plate chamber.

The experimentally determined emission efficiencies for several elements are shown in the accompanying table compared with predictions from the electron bombardment model.

Emission Efficiency
(amps/cm^2 for 1 rad/sec x 10^{-13})

Source	Al	Cu	Ag	Ta	Pt	Au
Co-60	1.7	2.0	2.2	2.5	2.3	2.3
Prediction	1.0	1.7	2.1	1.7	2.1	2.1

Prior to the experiments, the researchers believed that the predictions would hold within a factor of two and probably within 30 percent for most metals. The experimental results were encouraging in this respect. Note, for example, that the values predicted for silver, platinum and gold are within 10 percent of the measured values. The largest discrepancy is for aluminum where it is known that oxide layers have a strong influence on the emission.

DAMAGE IN SEMICONDUCTOR MATERIALS: The effects of impurities in semiconductor materials when exposed to radiation are being investigated. Objectives are a better understanding of the mechanisms of radiation damage in such materials. This understanding would provide a basis for better predictions.

One such study was of doped silicon irradiated with 1 MeV electrons. The effects of dopant type and quantity, oxygen content and dislocation density in the radiation damage process were investigated. Defects associated with such

Radiation exposures in the Laboratory must be done through remote control systems. Television is one of the tools used in the control of these experiments.

impurities as boron, aluminum, gallium, phosphorus, arsenic, antimony, and lithium were analyzed by several diagnostic techniques—Hall effect, electrical conductivity and minority-carrier lifetime measurements, electron spin resonance and optical absorption.

The largest single study of semiconductor damage, however, was devoted to radiation-induced defects in germanium cooled to low temperature. The Laboratory was interested in how these defects are annealed and assume different defect configurations as the temperature of the germanium is raised. In this study, germanium doped with 10^{18} arsenic atoms/cm^3 and cooled to five to ten degrees K was irradiated with 1.2 to 7 MeV electrons to introduce defects in the crystal. This permits the study of primary defects, interstitials and vacancies before the defects begin to move, anneal and produce different defect configurations.

In germanium, two temperatures are critical. Depending on the nature of the defect, annealing takes place near 35 degrees and near 65 degrees K. The primary defect which is introduced by irradiation at five degrees K is a close interstitial vacancy (I-V) pair, and this anneals at 65 degrees K. The defect that anneals at 35 degrees K is presumed to be a close I-V pair in some other configuration.

These two kinds of defect were studied from the standpoint of how their production is affected by bombarding electron energy. It was found that the interstitial vacancy type (that anneals at 65 degrees K) is highly energy dependent. Introduction of the defect increases almost linearly with increasing energy. The second type of defect is induced most readily at about 1 MeV and production falls off at higher energies.

This abridged account—actually an isolated example—of the Laboratory's research program on radiation damage to semiconductors can only hint at the complexity of the problem of understanding defects, dislocations, mobilities and annealing processes occurring in irradiated materials. When one begins to study these processes at temperatures above about 75 degrees K, one is confronted with another variable of great importance. This is because of the fact that above 75 degrees K defect configurations become increasingly dependent on the prior radiation damage history of the sample and on chemical and physical imperfections. Furthermore, defect parameters for each particular semiconductor are different. For each semiconductor material, there is a near-infinite set of variables that one would like to manipulate—dose rate, impurity concentration, impurity type, and so on.

DEVICE TOLERANCE: Radiation has many sources and can result in either temporary or permanent damage to a material. Low energy gamma rays, x-rays and electrons usually produce temporary damage by ionizing the material and in doing so create hole-electron pairs as added current carriers. Conductivity of semiconductors is then increased as long as the radiation lasts, but returns to normal shortly after it is removed and the free electrons recaptured. Bombardment by heavier neutrons and protons, however, can displace atoms from their normal crystal positions, thus creating permanent lattice damage. Of course, they can ionize as well, just as gammas, x-rays and electrons, given sufficient energy, can do permanent damage.

In the discussion above on damage to semiconductor materials, defects in bulk germanium and silicon were considered.

A silicon Hall bar, to be used for radiation effects studies, is being placed in a vacuum-evaporator system so that gold contacts can be evaporated onto the arms.

Because of its finite half-life, the Cobalt-60 gamma-ray source must be periodically replenished. This picture shows the delivery in September 1967 of 22,000 curies of radioactive cobalt.

But transistor action depends on the flow of electrons at the surface and at junction interfaces. By influencing electron flow at surfaces or interfaces of devices, radiation can impart additional effects on transistor characteristics.

AFCRL has studied the surface problem. Permanent degradation was observed in both insulated gate field effect transistors (MOS) and in planar bipolar transistors after short exposures to low energy electrons or x-rays. Under this program, the permanent degradation was found to be due to two effects of ionizing radiation. One was the build up of a positive space charge within the silicon dioxide. The second was the creation of fast surface states at the oxide-silicon interface.

After determining by experiments the dependence of these effects on radiation

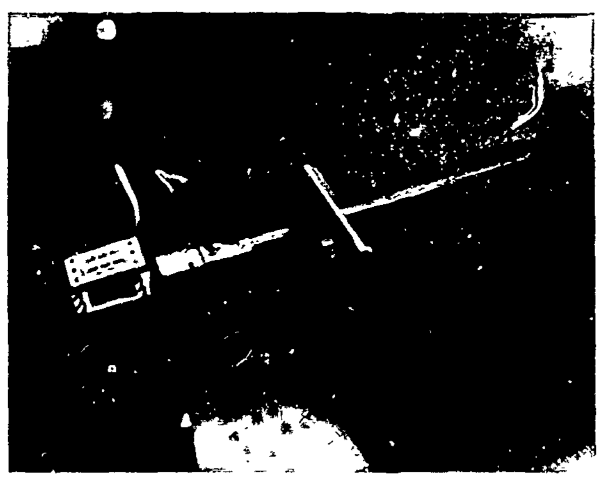
dose, on dose rate, and on applied bias voltage during irradiation, a theory involving hole trapping emerged which accounts for the observed features of the space charge buildup. Essentially the theory is this: Ionizing radiation, as expected, creates hole-electron pairs in the SiO_2; in the oxide there are large numbers of hole traps which capture the hole while the electrons escape and move independently with the applied field. When the radiation exposure is over, the holes stay trapped and cause neutralizing electrons to collect at the surface of the silicon below. In MOS devices, this caused large shifts in the operating point, and in planar transistors it caused increases in the leakage at the collector junction as well as variations in the breakdown voltage. The increase in fast surface state density resulting in an increase in the surface recombination velocity was shown to be responsible for the lowering of the transconductance of MOS transistors and for the degradation of low current gain in bipolar planar transistors. AFCRL hopes to obtain a better picture on the charge buildup in silicon dioxide. This may suggest new radiation tolerant dielectric materials as substitutes for SiO_2.

RADIATION TOLERANT DEVICE: Although bipolar transistors with high neutron radiation tolerance can now be produced and are available, further improvement will most likely come from the majority carrier field effect transistor. It was noted above that the MOS device suffers from space charge buildup in the gate dielectric when exposed to ionizing radiation. The junction field effect device (JFET) seems to offer greater resistance to radiation. Theoretical analyses of this device at AFCRL indicate an encouragingly high radiation tolerance.

Tests are being made of both commercially available types and those developed at AFCRL. They are being evaluated for frequency response, gain and noise, as well as radiation tolerance. Although testing was not far enough along to establish correlations at the conclusion of the reporting period, there is enough experimental information available to indicate the improved radiation tolerance that theory predicts.

ION IMPLANTATION: Radiation is not necessarily always a negative quantity. Radiation may be used to modify crystal structure in a favorable way in the fabrication of new devices. This new fabrication technology could also result in devices with higher radiation tolerance.

Ion implantation as a means for doping semiconductor materials has become of interest only recently, although it has seen commercial application in the making of solar cells. While ion implantation offers some very distinct advantages over diffusion and alloying as a means



A silicon Hall bar, fixed to an aluminum oxide substrate, is being mounted onto a test probe for Hall effect and conductivity measurements prior to irradiation in studies to determine the effects of radiation on semiconductor materials.

of semiconductor doping, many technical problems relating to reliability and yield must be solved before it can be used commercially for device production.

Ion implantation can be divided into two broad categories—low energy and high energy implantations. In low energy implantations (10–100 keV) one attempts to make use of the open channeling directions of an ordered crystalline lattice in order to obtain significant penetration of the ions. In high energy implantation (100 keV-5 MeV) one essentially considers the crystal as an amorphous substance and purposely avoids channeling directions. At AFCRL, work has been mainly concerned with high energy implantations. A Van de Graaff generator is used to accelerate the ions. Successful diodes have been fabricated using boron nitrogen and phosphorous implanted ions.

A unique characteristic of high energy ion implantation doping is that the maximum impurity concentration does not occur at the surface as in other diffusion techniques, but is inside the material. For example, using 2 MeV B^+ ions this maxima doping concentration is 2.5 microns beneath the surface. This allows one to fabricate n-p-n or p-n-p structures with just one implantation and to dope selectively in areas that are oxide covered. The AFCRL implantation is done through holes cut in a 1.5 micron thick gold mask. The targets have been both n or p type silicon covered with a 4000 angstrom layer of silicon dioxide. The thick gold stops all the ions while the oxide only slightly attenuates the ions.

A major advantage of the ion implantation process is that although the silicon sample must be annealed between 600 and 800 degrees C, depending upon the ion concentration and ion specie, one does not have to go to the high temperatures that are necessary for diffusion or alloying. This permits experiments with unusual dopants, such as nitrogen in silicon, which heretofore have never been successfully introduced into any semiconductor as a doner impurity.

THEORY OF THE SOLID STATE

Theoretical studies, as seen in the foregoing sections, are found in close association with many specialized efforts throughout the Laboratory. In this section several independent theoretical efforts will be noted. These efforts are not narrowly confined to the electronics solid state, but have potential impact across the entire realm of physics.

Ion implantation (in this case by a high energy boron beam) holds great promise for doping semiconductor materials. Here a new ion-implanted sample is being removed from the Van de Graaff accelerator target holder.

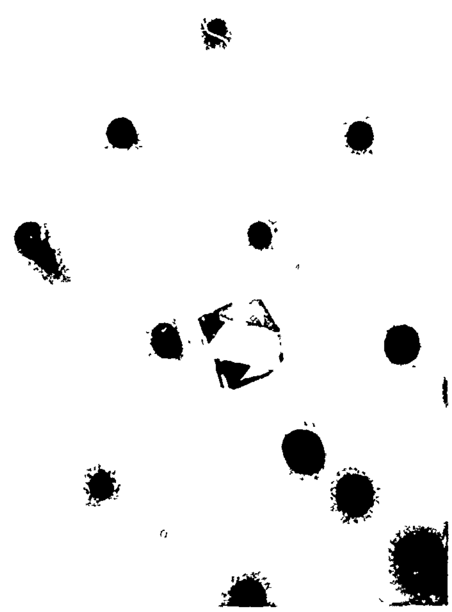
ENERGY BAND STRUCTURE: Band structure studies fall into the area of quantum mechanical theory. The AFCRL study is concerned with the restricted ranges, or bands, for the energies of electrons in solids. Electron energy levels in a solid give rise to the familiar band spectra of light and dark lines from which the spectroscopist identifies the various elements.

From the electronic energy band structure, many of the physical properties of crystals can be derived. Information bearing on the energy band structure finds ready application in the interpretation of a wide variety of experimental data, in the prediction of new solid state phenomena, in the clarification of the operating principles of various solid state devices, and in the design of new devices.

AFCRL is attempting to develop a physically reliable picture of such semiconducting crystals as silicon, germanium, diamond, silicon carbide and III-V compounds. The approach is to determine the band structure from first principles by a self-consistent energy band calculation, to test the theoretically predicted structure by experiment, and then to improve on the theoretical picture by an empirical adjustment so that it accounts for all relevant experimental information.

The starting point in these calculations is a non-relativistic, self-consistent energy band calculation based on Slater's free-electron exchange approximation. The novel aspect of this work is the introduction of an empirical crystal potential correction which compensates for the simplified treatment of exchange, and for the neglect of relativistic and many-electron effects. This provides a rational basis for constructing an extremely flexible adjustment scheme in terms of a minimum number of parameters. The energy band calculations on the major III-V semiconducting compounds have been completed. The next step is the calculation of the dielectric constants of these materials.

SOLUTION OF SCHRÖDINGER EQUATION: A new method has been devised for solving the Schrödinger equation for an arbitrary potential. The method also applies to other kinds of wave equations and wave phenomena—for example, the effect of a varying index of refraction on acoustic waves or of dielectric matter on electromagnetic waves. It, therefore, provides a new tool for calculating the reflection and transmission coefficients, phase shifts and scattering diagrams that are important for comparison with experiment in these problems.



The bonds between the atoms that make up a crystal determine to a large extent the mechanical, thermal, electrical and optical properties of the crystal. A substantial theoretical effort has been carried out for several years on the bonds that hold matter together in the solid state.

The novelty of the new method lies in its use of both the appropriate differential equation and its integral equation equivalent. The former has the virtue of possessing a formal solution, but does not guarantee the appropriate behavior of the wave amplitudes at infinity. The integral equation, on the other hand, does not have a simple formal solution, but does insure a proper asymptotic form. By combining these two kinds of equations then, their virtues are enhanced and their defects negated.

LATTICE DYNAMICS: The bonds which hold matter together in the solid state determine to a large extent the mechanical, thermal, electrical and optical properties of a substance. One way to study these bonds is by lattice vibrational spectroscopy. The AFCRL study covers crystalline dielectric solids. Infrared reflection and transmission spectra of these solids provide the basic experimental data. More recently, laser Raman spectroscopy and cold neutron scattering have become of increasing importance, but such measurements are so far available on only a few substances for the complete lattice vibrational region.

In the work discussed here, the ultimate aim is to explain and predict directly from lattice vibrational (infrared) spectra such properties as hardness, compressibility, elasticity, linear expansion, specific heat, refractive index extinction coefficient, and so on. Furthermore, it is the aim to develop simple relationships which show how each of these properties can be calculated and more important how they interrelate. To obtain data for the analytical studies, spectroscopic measurements were taken for the complete lattice vibrational region at temperatures from close to absolute zero to the melting point and for pressures which approach the destruction of the crystalline lattice. Measurements were made for AFCRL by outside contractors with the analysis and interpretation of the resultant data done by Laboratory scientists. During recent years, this work has resulted in more than 20 AFCRL authored papers published in the literature or presented at professional scientific meetings.

During the reporting period, a completely new approach was found for defining with precision the cohesive forces within a substance by the use of lattice absorption spectra. The new evaluation method is a powerful key for predicting and explaining linear expansion anomalies and the anisotropy of hardness. This method was reported for the first time in complete detail at the International Conference on Molecular Spectroscopy, Madrid, Spain, September 1967.

The foundation of the method is a concept known as the centro-frequency, a concept which was introduced ten years ago by an AFCRL scientist conducting the study. The centro-frequency is, in essence, the center of gravity of the infrared spectrum of a given material. In a step-by-step progression of mathematical expressions, the study shows the relationship of the centro-frequency to the material's specific heat, and to the material's elastic (acoustic) spectrum. It shows, as one example, the interrelation of specific heat to compressibility and of compressibility to the lattice cohesive energy. The equations demonstrate the key role of harmonic and anharmonic lattice vibration in the material. The analysis shows that there are two types of anharmonicity of the lattice structure which have a very different meaning in the atomic structure and that these two types have a pivotal function in the character of a material. Lattice anharmonicity, for example, is related to the repulsive forces between atoms, and can be used to predict the

change of compressibility of the solid with pressure.

THE THREE-BODY PROBLEM: A new method has been devised to treat the quantum mechanical three-body problem. The technique has already been applied to several problems in atomic physics where the three particles are bound together. For example, energies and wavefunctions have been computed for the ground state and some excited states of the helium atom and hydrogen molecule ion. It is believed that the method can be extended to treat three-body scattering problems as well.

The method consists of writing the total wavefunction for the problem as a sum of three parts. Appropriate expansions for each part are developed which converge rapidly. This means that a series approximation to the wavefunction is found such that, as more and more terms in the series are kept, one gets a better and better approximation of the exact result.

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VIII Microwave Physics Laboratory

The Microwave Physics Laboratory seeks to understand and solve the classical problem of the scattering and interaction of electromagnetic energy with natural and man-made environments. The problem has many aspects, each requiring specialized approaches. The Laboratory is engaged in antenna theory and design, to better control the transmission and reception of electromagnetic energy; plasma and environmental studies, to understand the propagation of electromagnetic energy; microwave acoustics and scattering, to enable the prediction of changes in the electromagnetic fields when they impinge on and reflect from material surfaces.

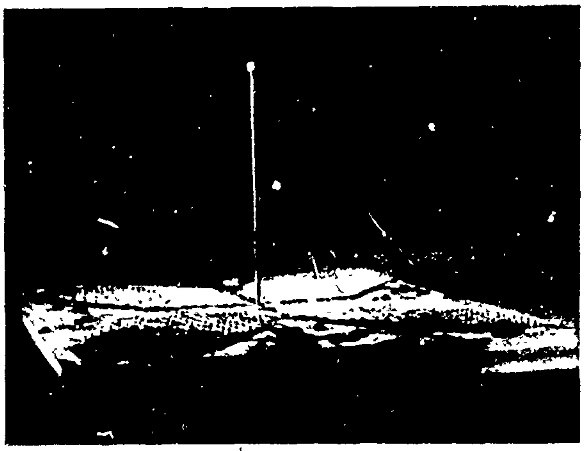
Several programs of the Microwave Physics Laboratory have evident potential for application in Southeast Asia. The reporting period was marked by a realignment of many efforts as the Laboratory tapped several of its main streams of research in radar, optics, antenna design and electronic circuitry for limited war applications. The problem of detecting ground vehicular traffic by an airborne radar is being attacked afresh through studies of electromagnetic scattering by lossy layers and resonant length objects. Coherence and statistical properties of the target are being used in phase comparison radars in search of better low frequency resolution techniques. The Laboratory is testing data processing antennas, multifrequency radars, methods of image enhancement and new kinds of radiometric instruments for better nighttime reconnaissance.

More general and longer range is work on high resolution antennas for

detecting and identifying space vehicles, millimeter wave research which focuses on the observation and prediction of solar flares and the atmospheric attenuation which influences earth-to-space transmissions. Other work includes new techniques in plasma propagation, the generation and detection of electromagnetic radiation by phonon interaction techniques, and the reduction of scattering cross section of missiles, making detection more difficult. The products of such research are new theories and techniques, more complete mathematical models to describe the electromagnetic environment, and ultimately new instrumentation and equipment.

ANTENNA THEORY AND DESIGN

The key word, descriptive of this Laboratory's efforts in antenna design, is *optimization*. The word implies a sensitive balancing between the desired performance goals and the real life conditions imposed on operating antenna systems. The goals are increases in antenna gain, resolving power, detection capability and the quality of radar maps of ground targets. Among the real life conditions that modulate these goals are limitations on aperture size, the cost of large antennas and signal distortions from natural sources—and, increasingly, from man's cluttering contributions to the background electromagnetic environment.



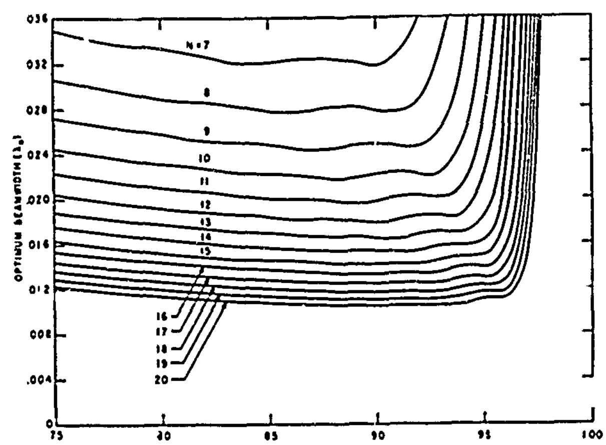
AFCRL's flat-plate antenna with an aperture of a half mile, a model of which is shown here, is a good example of antenna optimization. AFCRL scientists responsible for its design received the 1967 IEEE John T. Bolljahn Award for significant new antenna development.

GAIN, APERTURE AND COSTS: The 600-foot parabolic dish project of several years ago in West Virginia, abandoned when cost got out of hand, is a case of the prohibitive engineering costs in constructing certain kinds of large aperture, high-gain antennas. The high cost of large microwave antennas and the incremental cost that comes with each small increase in the resolving power of large antennas has held AFCRL's attention for many years. The best known consequence of this attention was the adoption of AFCRL techniques for the design of the 1000-foot Arecibo Radio Telescope in Puerto Rico. The costs of large antennas are largely engineering costs, particularly in the construction of large steerable dishes. The Arecibo telescope obviates many of these costs, as does the AFCRL flat-plate array, discussed in previous reports. These methods provide large aperture areas at low cost by shifting the design burden from the mechanical to the electrical side of the problem.

With respect to the flat-plate array, with its half-mile aperture, Laboratory scientists throughout this reporting period were called upon for data and for personal briefings by various DoD agencies, NASA and private university

groups. In spite of continuing interest, no plans currently exist for constructing a full-scale operational antenna based on this principle.

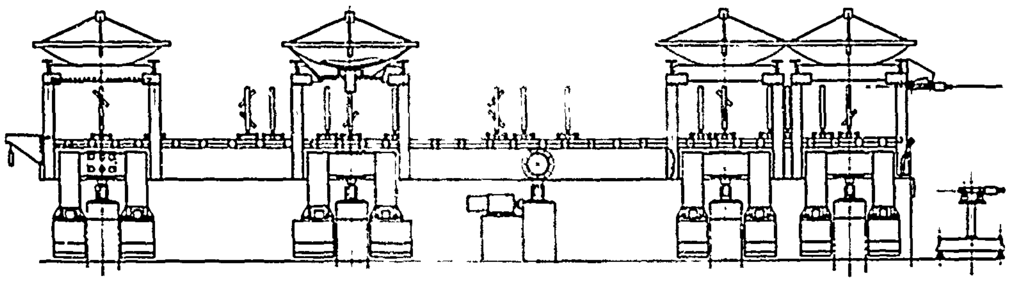
The approach for realizing high resolution at low cost currently receiving most attention is the optimum utilization of a given aperture area or number of elements for a specific application. For example, if one were using 100 dipoles for mapping targets, one must decide whether better results would be obtained by grouping the elements closely or by spreading them apart. Studies of this topic have led to a theory of optimization for the antenna element distribution in space which is now undergoing two experimental tests here at AFCRL.



As the number of elements in an antenna array is increased, a narrower beamwidth (and thus higher resolution) is obtained. Optimum pattern width may be achieved for uniform element spacings that are larger than .9 of the wavelength but smaller than one wavelength.

SIGNAL ENHANCEMENT AND PROCESSING: Of equal importance to the lowering of the basic antenna cost and the optimization of the antenna configuration is extracting maximum information from the output data. The raw output of an antenna system is rarely in the best form for presentation or use. Processing of the antenna output in two steps can yield significant improvements in the quality of the target images. The first step in angular data processing is to restore the components of the input frequency spectrum that were reduced or distorted by the antenna. While it is true that the restoration process can never add frequency components that were not actually received by the antenna, the existing data can be sharpened by this process at the expense of generating some unwanted lobes or overshoot oscillations. The restoration process, when applied to images of incoherent (uncoupled) sources or targets, has two undesirable aspects. The restored output tends to contain a good deal of ripple, which obscures small returns, and second, blanking lobes are generated in the vicinity of large narrow targets. These blanking lobes, which correspond to negative returned power, can hide small targets that are close to the large ones. A second processing step, the enhancement of the angular data, can reduce these effects. The enhancement process requires that the final output contain no blanking lobes. To achieve this, spectral components are added to the restored data so that the final distribution does not exhibit the sharp spectral cutoff that produces the Gibbs or ripple phenomenon. Two antennas based on these techniques are discussed below.

THE MILLIMETER WAVE ARRAY: A 28-foot linear array of four parabolic reflector antennas was under construction at AFCRL as of June 1967. Each reflector is four feet in diameter. The four reflectors are spaced in such a way that the array functions as one unambiguous seven-element interferometer. Operational wave length is 2 mm, resulting in a resolution of better than one minute



The four reflectors of this array are spaced in such a way that the array functions as a seven-element interferometer. The array, under construction as of June 1967, operates at 2mm wavelength (140 Ghz). Each dish measures four feet across. Length of the array is 28 feet.

of arc in right ascension. The reflectors are fed by a novel arrangement of beam waveguides and mirrors that will result in a flexible and efficient feed structure for the 28-foot long array. Because heat and cold could distort the precision alignment of the array, the entire structure will be housed in a temperature-controlled shelter. Also, because minor vibrations could affect the extremely short wavelength system, the array is mounted on a heavy base with deep foundations.

The experimental millimeter wave array represents a new and potentially important application of beam waveguide technology. If the intended methods of mode control are successful, a means for developing high efficiency feeds for large millimeter wave phased arrays will have been demonstrated for the first time. The flexibility of the feeding structure permits the millimeter wave array to be used as a test bed for antenna technology in this frequency range. The arrangement of the reflectors for a flat spatial frequency transfer function permits the test of this type of array as a mapping device in a realistic environment.

In addition to demonstrating the feasibility of new principles, the finished instrument will be used for experiments in the 2 mm wavelength band, a region of the spectrum relatively unexplored. Studies of atmospheric absorption and scintillation as well as astronomical experiments can be conducted with this array. Completion of the structure and test of the electromagnetic portion of the device is scheduled for January 1968.

THE HF MAPPING ARRAY: The millimeter wave array discussed above will test the principles of optimization as applied to an array of elements arranged along a line. The theory applies also to a two dimensional aperture distribution. To verify these concepts for a planar array, an antenna operating at frequencies between 5 and 7.5 MHz has been built in Sudbury, Mass., and will be tested in mid-1967. This antenna will be among the first two-dimensional arrays using the concepts of the antenna transfer function and spatial frequency in its design. It consists of 103 dipoles arranged roughly in a circle with a radius of approximately 1000 feet. Each dipole is connected to a central receiver through a pre-amplifier and an 1150 foot length of a co-axial cable. The antenna's three degree beam can be

scanned and mutual impedance compensation introduced electronically at the central receiver.

At low frequencies the ionosphere distorts the wavefronts of electromagnetic waves passing through it. This phenomenon changes the apparent transfer function of the antenna and corrections must be incorporated into an effective transfer function which will then be used in the processing of the antenna output. Maps of the radio sky will be digitally processed to restore the spatial frequency spectrum to its most probable value. The records will then be enhanced to provide a physically realizable output.

The frequency region of 5 to 7.5 MHz at which this antenna operates is of particular interest to the radio astronomer. No high resolution radio telescope exists for this region although many radio stellar sources are strong emitters in this region. The frequencies were chosen for this reason. After the Microwave Physics Laboratory scientists have finished testing the capability of the array, it will be turned over to AFCRL's Space Physics Laboratory for operation by radio astronomers as a radio telescope.

AFCRL's 7.5 MHz antenna array at Sudbury, Mass. has a diameter of about 2000 feet. By using a computer to correlate the output from the elements, high resolution is obtained.

RADAR MAPPING: As operating frequency is changed, a single antenna-target pair acts like several different pairs, each with its own characteristic behavior. Thus, the total target information returned to the radar is increased in a fashion quite analogous to the use of color photography in an optical situation. Current efforts in the Laboratory are directed toward capitalizing on this effect. The approach is through multi-frequency operation, using the frequency dependent antenna transfer function with the intent of applying the analysis to airborne radar mapping.

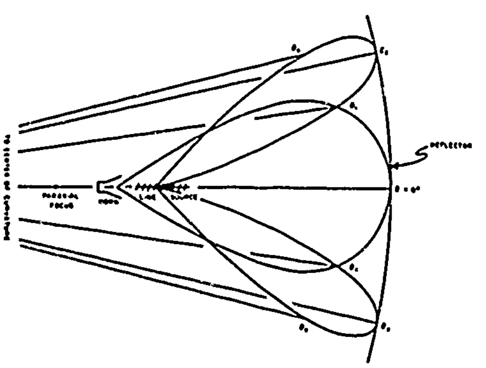
Classically, a radar transmits a pulse or a cw signal generated by an oscillator at some discrete frequency. But suppose this signal is modulated in some special way? Is it then possible to derive additional information about the target? In a contractor study on the potential of this hypothesis, a new coherence theory, suited to man-made information carrying signals, was developed. This theory of controlled radiation sources is contrasted to optical coherence theory in which the signals are as nature provides them. Proper processing of the received signals, making use of any *a priori* information available about the transmitted signals or the target statistics, shows that both fidelity and resolution are increased. A primary application of this technique is in high resolution radar mapping.

REFLECTOR ANTENNAS: Most antenna systems employ a feed system located in the vicinity of the focal region of a reflecting surface. Such systems usually represent a compromise between

uniform aperture illumination (required for maximum efficiency) and tapered primary feed systems designed to minimize spillover (that part of the energy from the feed which never reaches the reflecting surface). In general these systems are designed with little or no regard for the field distributions in the vicinity of the focal plane.

For many years AFCRL has conducted theoretical and experimental investigations of the tranverse focal reg on field distributions and various feed systems for Gregorian, Cassegrain and spherical line source systems. The objective of this work is to regulate radiation characteristics.

In the Cassegrain systems the main parabolic reflecting surface is fitted with an array of feed horns at the vertex and a hyperboloid is used as a subreflector. The phase and amplitude of the field distribution in the focal plane can be controlled by adjustment of the phase and amplitude of the horn array system and by proper choice of the hyperbolic subreflector parameters.



The Laboratory has pioneered in development of line-source feeds for correcting aberrations of spherical reflectors. With both a horn and a line-source feed, more effective use is made of the available reflecting surface. This dual feed mechanism has been proposed for use with the Arecibo Radio Telescope.

The Gregorian system employs a spherical reflector and a shaped subreflector with a horn source through the subreflector vertex. Proper choice of amplitude and phase distribution between the spherical r ctor and subreflector permits regulation of the radiation characteristics of the system. Since the Gregorian system is symmetrical with respect to the system axis, large scan angles can be obtained by movement of only the relatively small subreflector system while allowing the large main spherical reflector to remain stationary. This has a great advantage over the parabolical reflector system when the main reflector is large and mechanically difficult to rotate due to weight and size.

Another scheme developed at AFCRL for obtaining large scan angles for large aperture spherical reflector antennas is the sphere-line source system. (One such system was developed for the Arecibo Radio Telescope.) In this system a line source in conjunction with a horn is used as a point source. By properly choosing feed positions and by limiting the amount of surface illuminated by each of the feeds, relatively high efficiencies may be obtained and large scan angles can be secured by movement of the horn and line source system. In general it has been demonstrated that reflector antennas can be designed with special feed systems capable of reducing side lobe level and spherical aberration while permitting regulation of the radiation characteristics of the antenna system.

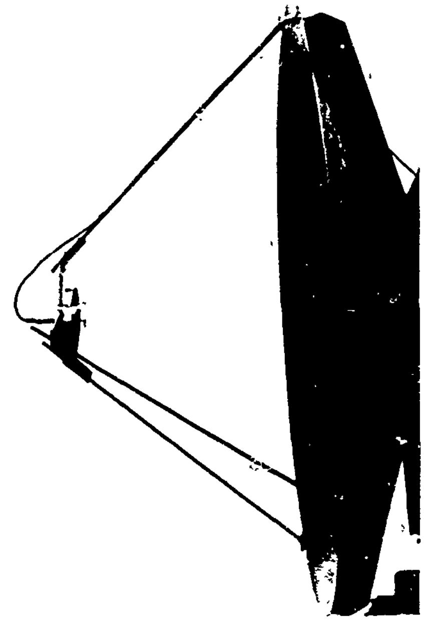
SHORT-BACKFIRE ARRAY: The "short-backfire" antenna is a novel antenna concept that originated at AFCRL. It consists of a flat plate of two wavelengths diameter, with a circular quarter-wave rim, a dipole feed spaced a quarter-wave in front of the flat plate

and a smaller flat plate spaced another quarter-wave in front of the dipole. The system acts like a partially opened cavity. Formed into an array, the short-backfire antenna produces the same gain as a dipole or slot array for the same overall aperture area, but with a small fraction of the number of elements required. During this reporting period, several important results in applying this promising antenna concept have been accomplished.

A study of the amplitude and phase distribution in the nearfield of the backfire antennas has shown that even complete enclosure of their structures by a metal cylinder of the diameter of the larger plane reflector, and long enough to extend over the entire length of the backfire element, does not degrade antenna performance. Instead, the resulting closed circular cavity, with the partly open end as the antenna aperture, was found to be especially useful in flush-mounted high-gain applications for airplanes and space vehicles. The flush-mounted short-backfire extends only about a half wavelength into the skin of the vehicle body, and still produces gains of more than 16 db with a single feed and a cavity depth of two wavelengths. With several such short-backfire elements arranged in a large size cavity of half a wavelength in depth, gains of even 20 to 30 db can be obtained.

Tests showed that a single short-backfire element can replace ten dipole elements, making a significant reduction in antenna complexity. A most significant result is the reduction in the number of separately fed array elements thus decreasing the internal losses of large arrays and markedly increasing their gain and efficiency.

The low side and backlobe level and the almost identical shape of the E and H plane patterns indicate the feasibility



The short backfire antenna is extremely versatile and can be used as a feed mechanism for a parabola (above) or as a flush-mounted antenna in which the antenna consists of a cavity in the body of an aircraft or a missile.

of the short-backfire antenna as an efficient feed for paraboloidal antennas. The secondary radiation patterns have very low side and backlobe levels which correspond favorably to the primary patterns with all sidelobes at least 27 db, and the backlobe more than 40 db below the amplitude of the main beam.

Another version of a short-backfire feed for paraboloids is the monopulse feed. It consists of a group of four short-backfires in front of a two wavelength plane reflector. The sum and difference patterns indicate the extremely sharp nulls which are desired for accurate tracking of space vehicles.

LIMITED WARFARE

The Microwave Physics Laboratory in 1966 initiated, and has since vigorously pursued, a new program under project SHEDLIGHT directed toward the radar detection of military targets which are hidden under a jungle or foliage canopy. Scientists are seeking to understand both the physics and the measurable aspects of the electromagnetic scattering phenomena in order to design new instrumentation capable of locating and identifying objects in vegetation type clutter.

LOW FREQUENCY TECHNIQUES: Ground vehicles scatter electromagnetic energy very strongly at radar wavelengths about equal to their dimensions (the resonance effect). Such wavelengths are longer than those normally used for airborne radar reconnaisance. But in addition to the resonance effect, the lower frequencies penetrate jungle foliage while microwave frequencies do not. Because antenna patterns are relatively broad at these lower frequencies, the usual scanning and beam pointing methods are ineffective for target location.

A novel AFCRL technique employs phase comparison in broad antenna patterns for electronically locating targets in angle without antenna motion. Such equipment is being tested at AFCRL's Ipswich facility where a high-power radar can be rotated to overlook land or sea and thus determine the capability of the radar to detect and locate large metal targets against various types of background reflections. These in-house experiments are preliminary to the design of airborne instruments. The airborne antenna designs are just taking form in the Laboratory with attention devoted to decoupling techniques which achieve the control of the antenna phase center location necessary for phase comparison radar.

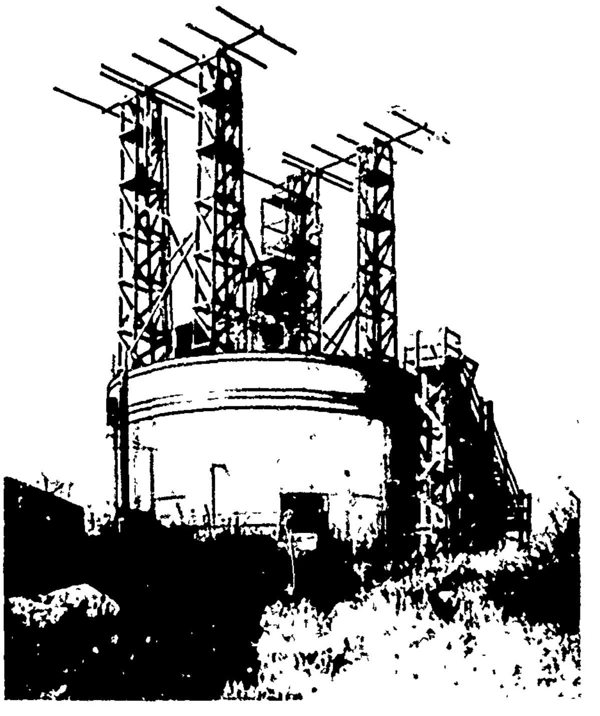
One disadvantage of low frequency operation is the loss of resolving power in the broad antenna patterns. A new approach to this problem is through linear frequency modulation. This is a process similar to that used by bats in their navigation and insect detection systems. AFCRL has demonstrated through microwave experiments that increased angular resolution can be achieved in a passive, low frequency, two antenna system. Mixing the two frequency-swept antenna signals produces a constant frequency, difference signal which serves as a measure for the angle of arrival of the incoming wavefront. The number of these signals, hence the number of angles of arrival which can be handled by the system, is limited only by the number of difference frequency analyzers available.

The advantage of frequency sweeping is that the system resolution is proportional to the sweepwidth used and to the antenna separation. For any antenna separation, the extent to which the oper-

ating frequency can be swept is limited only by instrumentation. Single frequency phase detection systems are subject to ambiguities, but the method of measuring frequency differences produces no angular ambiguities. The combination of swept frequency operation with antenna separation promises to increase resolution and to enhance detection of metal targets.

The swept frequency antenna system is identical, in principle at least, to constant frequency antennas which are mechanically moved or swept in parallel but opposite directions. The system resolution in this case is proportional to the received frequency as well as to the mechanical sweepwidth of the antennas.

The frequency sweeping concept can also be used in radiometric receiving systems detecting thermal or noise sources distributed in angle. In this application, one only needs to sweep the local oscillator frequency of the radiometer. Research in this area resulted in the development of a general method for achieving extreme linearity in frequency sweeping.



This experimental HF Yagi antenna array was used at the Laboratory's antenna range to evaluate the effectiveness of phase comparison radars for improved target discrimination.

ELECTROMAGNETIC SCATTERING ANALYSIS: An analysis of metal objects placed in a natural vegetation background has been carried out. One scientist at AFCRL has considered the case of electromagnetic waves impinging from near normal incidence on a three-layered model consisting of earth, jungle and air. He analyzed the effect of the frequency selective jungle with and without metal objects on the lossy ground. Remarkable and hitherto unobserved spikes in the frequency versus amplitude and phase curves are obtained.

To locate and identify ground targets, the power scattered from the target must be large relative to the clutter power scattered from the interferring medium surrounding the target. In another investigation, analytical studies were performed to determine frequencies, polarizations and radar look angles at which the ratio of signal to clutter power is maximized.

In these studies, a target was chosen so that its frequency response and scattering pattern are representative of the class of resonant targets to be detected by the radar. Experimental observations of the radar reflecting properties of various types of terrain were used to obtain analytical expressions for the average clutter power reflected by a pulsewidth-beamwidth limited area on the earth. (For discussion of additional work on remote sensing of terrain, see Chapter

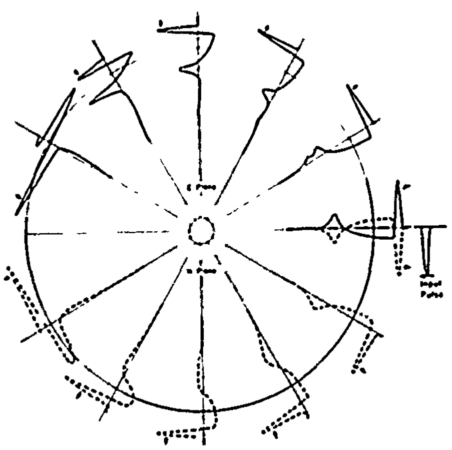
IX.) The results emphasize the importance of resonance region frequencies and low elevation angles for enhancing detection.

Another group of investigators is exploring a method of using the phase information present in the incoming radar signal (phase in the time stream) for detection purposes. The analysis shows that the stability of the phase versus time function allows one to distinguish single strong echoes from those produced by an ensemble of neighboring targets giving the same amplitude radar return.

CLUTTER REDUCTION METHODS: The effects of clutter can be reduced either by processing the returned radar signal or by modifying the characteristics of the transmitted signal. Recent work done in microwave coherence theory indicates that the latter technique is relatively easy to instrument and may be of significant value in improving radar performance. The return from clutter—due to trees, ocean waves or any extended distribution of small scatterers—is highly decorrelated. The microwave signal intensity varies over wide limits from one instant of time to the next. When a target is immersed in a clutter producing background, the total signal received at the radar is the sum of the target return (which is relatively constant as a function of time) and the clutter. If conditions are such that at one instant of time the clutter is greater than the target return, the target will remain undetected. An instant later, however, the situation may be reversed. Clearly, the more often the latter situation can be brought about, the more probable will be the detection of the target. If the average power from the target is equal to or greater than that from the clutter, then decorrelating the transmitted signal will greatly reduce the clutter fluctuations. System performance will thus be enhanced.

In another Laboratory project, a radar simulation device is being constructed. It will be used to determine the operating capabilities of a two-antenna, phase comparison detection system. An intensive study of methods for generating artificial target-in-clutter signals and reducing the clutter effect in phase detection systems is envisioned. The simulator will also be used to explore improved techniques for the presentation of target information.

It is also possible to utilize the difference in the coherence effects between a single target and an extended clutter background for detection purposes. This approach incorporates new theories (originally developed for a transmission line with randomly placed discontinuities) of partially coherent reflections from ground scatterers. The transmission line results can be transformed to the angular domain and used to analyze the phase comparison type radars. With



The approximate impulse response of a perfectly conducting sphere is illustrated as a function of the observation angle around the sphere. Results for the planes containing the incident electric (E) and magnetic (M) fields are shown.

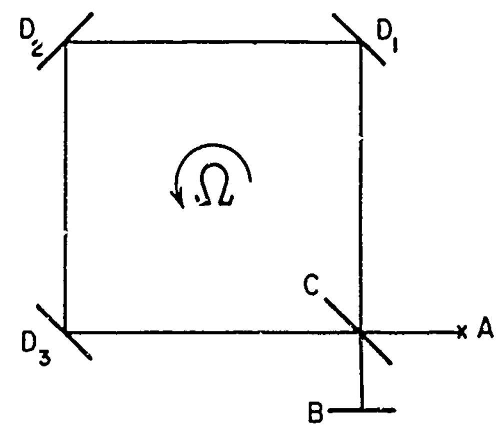
frequency or noise modulation on the transmitted radar signal and the use of correlation devices on reception, improved target visibility appears possible.

The foregoing research, undertaken in direct response to limited war needs, has already resulted in a number of unique approaches and techniques which promise to have widespread applications in addition to those more immediately associated with Southeast Asia.

ELECTROMAGNETIC FIELD THEORY

Laboratory projects in electromagnetic field theory range from classical field theory associated with accelerating physical systems, through aspects of wave propagation and coherence theory, to investigations of electromagnetic scattering from objects. Theory is coupled with experiment to prove validity and to show limitations. This Laboratory has provided a great deal of the basic coherence theory now widely used and has pioneered in coherence experiments at microwave frequencies. It has sponsored national symposia in this field, and a Microwave Physics Laboratory scientist was editor of the *IEEE Transactions on Partial Coherence Theory* published in January 1967.

ELECTROMAGNETIC THEORY AND MOVING SYSTEMS: When electromagnetic cavities are accelerated, the phenomenon of resonance splitting occurs—that is, the cavity resonates at two distinct frequencies. A study of this phenomenon showed that there is a very intimate relation between this resonance splitting and some interesting unipolar induction effects. It is known that resonance splitting in cavities can be used in devices for sensing rotation. At present, the Laboratory is investigating to what extent the unipolar induction effects can be used in such devices.

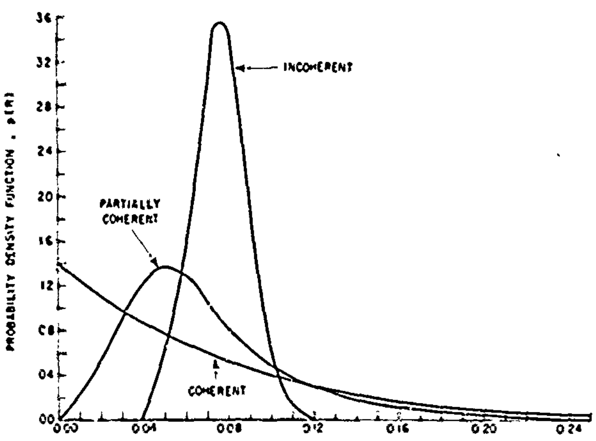


The Laboratory plans to repeat the classic Sagnac experiment using the interferometer diagrammed here. The light beam in a rotating system is split with half mirrors and is sent in opposite directions. The reunited light produces a fringe pattern. Purpose of the experiment is to evaluate the feasibility of an optical system for detecting acceleration.

Under AFCRL contract, a ring interferometer is being constructed. It will be used to perform a high precision repeat of the Sagnac experiment which is concerned with rotating electromagnetic fields. Preparations are also underway to construct a precision ring laser which will enable Laboratory scientists to study the limitations of this device due to mode locking, mode pulling and the effects of optical media in the light circuit.

Another effort has been directed toward the problem of radiation reaction for the elementary charged particle. A redefinition of the problem has led to a curious dynamic principle which was first proven in a weak form for the radiating dipole by von Laue in 1908. Scientists at AFCRL have shown that it also holds in the more general case of radiating electrons. The analysis has resulted in a new picture of the classical electron, combining the traditional point charge with an extended energy structure.

WAVE PROPAGATION: A fresh perspective into the propagation of waves through a medium is gained by classifying cases according to whether the medium or the source of the waves is random or nonrandom. The classification scheme presents a unified viewpoint so that propagation problems which appear rather isolated and independent can, in fact, be treated in a systematic manner. The waves can be of any variety—electromagnetic, pressure or elastic. If one considers electromagnetic waves, the relationship between partial coherence theory and the general subject of wave propagation can be developed. Partial coherence theory sets up relations for the propagation of a mutual coherence function, which is related to the actual disturbance or wave function in a fairly complicated way. The general analysis described above, however, uses the wave function itself as the quantity of prime interest and all results, therefore, show the dependence of the propagation on this wave function.



The probability of obtaining a specified power reflection coefficient from a random collection of scatterers, depends on the coherence properties of the microwave signal used. As the signal becomes less coherent, the range of power reflection coefficients decreases considerably.

The four classification categories are: both medium and source nonrandom; medium random, source nonrandom; medium nonrandom, source random; medium and source both random. The randomness can be both in space and time. A representative case of a random medium and a nonrandom source is the multiple scattering of a monochromatic wave by a random collection of scatterers. A case in which the medium is nonrandom and the source random is exemplified by the theory of partial coherence. The most general case, in which both medium and source are random, corresponds to situations found in nature such as electromagnetic wave propagation through a turbulent atmosphere, light propagation through ground glass, and underwater sound propagation.

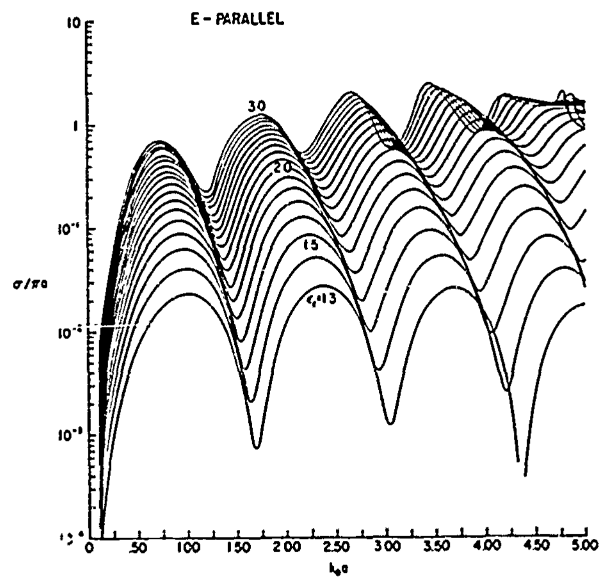
An AFCRL scientist has shown that the general case, which covers all the other cases, can be solved by a perturbation method. It is a powerful method which accommodates nonstationary and nonhomogeneous problems such as random processes of stationary increments or random fields with local homogeneity. Because the analysis treats the most general case, it promises to be of significant value in analyzing problems in radar and communications.

PARTIALLY COHERENT MICROWAVE FIELDS: During the reporting period experiments relating to partially coherent microwave fields were performed with significant results. Generally, the studies can be divided into two groups: those to establish or verify predictions (derived from optical considerations) about the behavior of partially coherent microwave fields, and those to explore the response of microwave systems to such fields.

Optical theory predicts that when two beams of unmodulated, partially coherent, quasimonochromatic light having large optical path differences are superposed, the resulting power spectrum is modulated (Alford and Gold effect). Optical workers attempting to observe this theoretical result under actual laboratory conditions were, until the AFCRL experiments, unsuccessful. This effect was first observed in an experiment performed by AFCRL at microwave frequencies. Microwave fields can also be used to determine the limits of validity of partial coherence theory. Several AFCRL experiments have verified criteria, previously only suspected. In one such case, experiments enabled scientists to show that quasimonochromaticity and spectral purity are distinct rather than interdependent phenomena. In another experiment, the modification of the radiation characteristics of several types of antennas illuminated by partially coherent fields was measured. The results were found to agree well with theory.

In another area, new theories which describe the reflection of electromagnetic energy from a distribution of random scatterers were put forth. The results are expressed in terms of the characteristics of the illuminating energy, the scatterers, and the loss mechanism of the propagating medium. Experimental verification of the theory has been accomplished using a long transmission line.

RADAR CROSS SECTION CONTROL: Theoretically, it is possible to design a ballistic missile—or other vehicle——of relatively large size that cannot be readily detected by radar. But designing a practical vehicle having a low radar cross section (that is, one which is difficult to "see" with a radar)



It is possible to determine the shape of an object from an examination of its radar return, assuming that the reflected object has a simple geometric configuration. Backscatter cross section of an infinite dielectric cylinder is depicted above. Presently beyond the capability of researchers is the reconstruction of the shape of models such as the vehicle shown below because of its several compound curves, edges and corners.

is another matter. The designer does not have full freedom to configure the vehicle for a minimum radar return because his design must be compatible with aerodynamic and mission requirements. Quite apart from this problem, the mathematics of the situation are formidable. When the vehicle shape contains edges and corners and is illuminated by radar wavelengths about the same size as the vehicle's dimensions, there is at present no mathematical technique for solving the electromagnetic scattering problem. In fact, the scattering problem associated with almost any shape other than a simple sphere is as yet unsolved. Most practical vehicle shapes are very complicated and attempts to control their radar characteristics ultimately revert to an experimental cut and try process. This method is expensive and time consuming since it requires models machined to a high mechanical precision and very reliable experimental measurements.

The mathematical solution, if it is to be achieved, will be achieved only through new methods for solving electromagnetic boundary value problems. Currently, the Laboratory is emphasizing two theoretical techniques. One of these is an approximate procedure based on an extension of the geometrical theory of diffraction. This geometrical theory is most accurate when the object is large compared to the wavelength. More recent work, however, conducted under AFCRL contract by Ohio State University, indicates that it may be possible to extend the theory to give more accurate results for smaller objects. In addition, methods of evaluating certain diffraction coefficients experimentally could result. This would extend the applicability of the geometrical theory to much larger classes of scattering objects. The second theoretical technique is aimed particularly at objects with edges and corners. Cubes provide the best test objects for this analysis in which advanced mathematical techniques are applied to rigorous electromagnetic theory.

PLASMA ELECTRODYNAMICS

Plasma electrodynamics research is focused on the problem of the plasma sheath. This sheath of ionized gases which forms about a space vehicle upon reentry into the earth's atmosphere can sever communications with the spacecraft. This problem is not critical for manned ballistic reentry vehicles, such as the Gemini or Apollo capsules, since the communications blackout period is relatively brief. However, renewed Air Force interest in lifting or glide reentry vehicles, for which the blackout can last for substantial periods (up to 20 minutes) has redirected the search for solutions to the reentry communications problem. Simple voice communications are far less critical than the need for relaying telemetered ground control information to the vehicle to guide it through its critically narrow reentry corridor.

Because no one solution can cover all aspects of the problem, a broad research program is being conducted, with heavy emphasis on theory. This program ranges from studies of the basic processes in ionized gases to rocket tests of experimental antennas and communications systems.

ALLEVIATION TECHNIQUES: Conventional solutions for alleviating the reentry communications problem are many—and these solutions represent the efforts, in the aggregate, of a sizable segment of the aerospace industry and Government laboratories, including

During the period, several rocket experiments were conducted to measure radio attenuation by the plasma sheath that envelops the nose cone during the reentry.

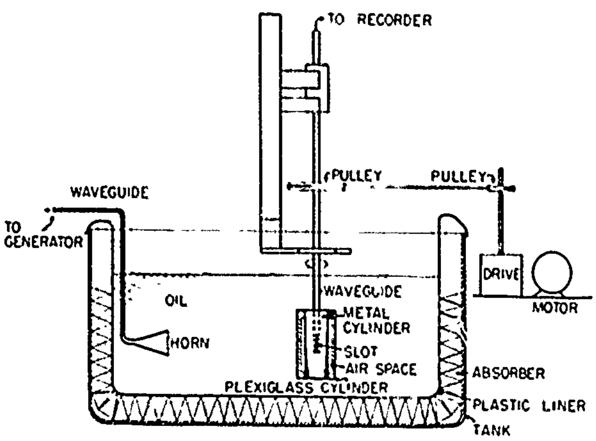
AFCRL. Some of these solutions are: the creation of new, low attenuation propagation modes within the plasma sheath through the use of magnetic fields or electron beams, reduction of electron density by aerodynamic shaping of the vehicle, by the addition of various chemicals, and by operation at frequencies above the critical plasma cutoff frequency.

A technique, developed by AFCRL scientists as the result of basic studies of radio wave interactions with oxygen plasmas (described in the previous AFCRL Report on Research), offers a possible solution to the reentry communications problem which may be superior to other techniques, especially for long-duration flights. This approach involves the irradiation of the plasma in the expansion region of the flow field by radio frequency energy in order to increase the attachment rate of the electrons to the oxygen atoms. The negative oxygen ions which result from this attachment are so massive compared to electrons that they do not influence microwave propagation through the plasma. This results in a reduction of the effective plasma frequency and an improvement in signal transmission through the sheath. The effectiveness of this alleviation for high temperature flow fields will be explored experimentally in the coming months through the use of the Laboratory's new arc jet facility which operates at reduced atmospheric pressure.

Several AFCRL contractors are exploring a range of chemical additives to test their effectiveness in reducing the electron concentration in ionized flow fields. These studies have shown that, in agreement with results obtained by NASA using water injection, liquid droplets of several chemical additives can be more effective than injection in the form of vapor. Sulfur hexafluoride produces slightly better reduction in transmission losses than other gaseous additives tested. But other related compounds, such as Freon C-318, react faster with the plasma and therefore may give better performance in a high velocity flow field.

PLASMA SIMULATION TECHNIQUES: Many new laboratory facilities for exploring changes in antenna performance under reentry conditions have been assembled over the past several years, both by AFCRL and its contractors. These facilities permit scientists to conduct plasma simulation experiments, to produce plasmas by microwave and dc gaseous discharges, and to conduct wind and shock tunnel tests.

Preliminary tests of low power microwave transmission through the reentry plasma sheath have been completed at



Oil is an attenuator of EM energy and can be used to simulae plasma sheath in the laboratory. This schematic shows an oil tank used by AFCRL for such experiments.

both Cornell Aeronautical Laboratory's shock tunnel and MIT's modified supersonic wind tunnel facilities. The modification to the MIT wind tunnel incorporates a DC arc jet in the test models to raise the heat content of the incident flow fields. These tests demonstrate the behavior expected of plasma-covered antennas with respect to impedance and radiation pattern distortions. Analytic studies, conducted at M.I.T. in conjunction with the wind tunnel experiments, have demonstrated the important role of convective losses in reducing the power-handling capability of microwave antennas during reentry.

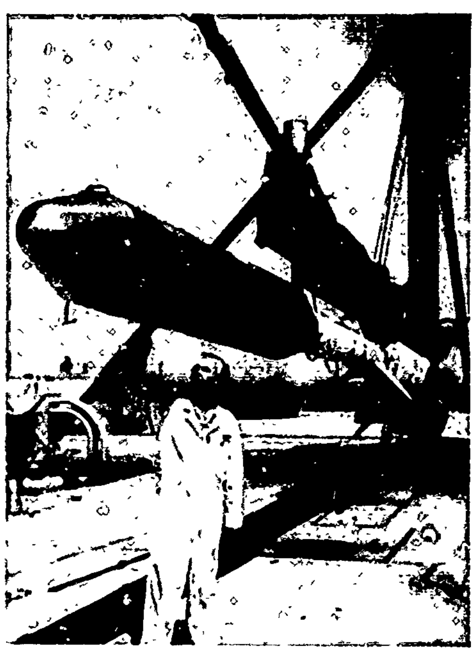
Several other plasma simulation facilities, using hot cathode or surface wave gaseous discharges, have been developed by AFCRL contractors specifically for studies relating to ballistic missile technology. Radiation patterns of several aerospace antenna configurations, such as slots on conical bodies, have been measured in the AFCRL liquid dielectric plasma simulation chamber as an independent check on these results.

ROCKET PROGRAM: During the period, the Laboratory instrumented two types of rockets under two different test programs. These were the Trailblazer rocket for reentry communications studies, and the Nike-Cajun for antenna voltage breakdown studies.

For three scheduled Trailblazer flights, the basic experiment consists of high-power S-band equipment to measure the non-linear response of the reentry plasma sheath to intense microwave radiation. The experiment will provide flight test results as an independent verification of laboratory studies of the power-handling capabilities of microwave antennas in the presence of ionized flow fields. A new type of plasma diagnostic probe, based upon principles of electroacoustic wave propagation in warm compressible plasmas, was developed at the Sperry-Rand Research Center and is included in the Trailblazer communications payloads. The payloads were also designed to provide measurements of such antenna parameters as pulsed signal degradation, mutual coupling effects, and impedance changes. The first of the Trailblazer vehicles was flown from the NASA rocket launch facility at Wallops Island, Virginia, in June 1967.

A Nike-Cajun rocket was launched in April 1965 to measure antenna voltage breakdown. Purpose of the test was to compare the performance of an x-band slot antenna with that of a VHF quadraloop antenna. The x-band slot antenna withstood breakdown better than expected while VHF quadraloop antennas, mounted on the same rocket, fared worse than expected. Also, both antennas suffered breakdown occasionally at altitudes above 250,000 feet, a region where such behavior was unexpected. Judging from Laboratory vacuum chamber measurements made since the flight, it is likely that this spo-

The placement of antennas on the nose cone used for AFCRL's reentry communications test are shown in the photo above. AFCRL's antenna voltage breakdown experiment was conducted using the rocket shown below.



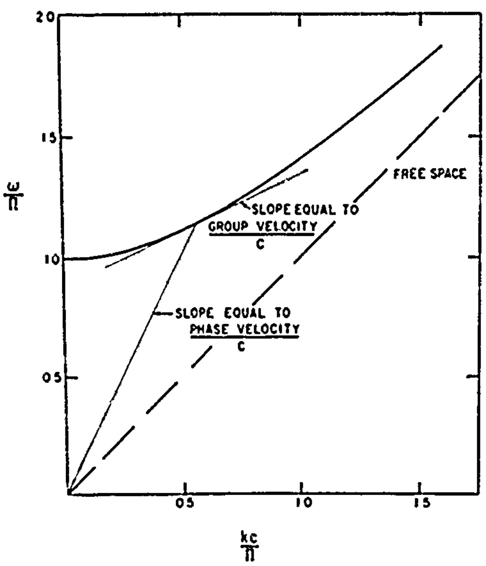
radic breakdown was due to outgassing from the vehicle or to contamination on its surface. Breakdown of the x-band antenna occurred cyclically; the cyclic variations showed a correlation with the roll rate of the rocket. It is probable that antenna breakdown occurred more easily when the antenna was exposed to the sun. A second rocket is scheduled for launch in the latter part of 1967. The power output of the x-band transmitter will be increased, and the instrumentation will include a photoelectric sensor to indicate when the antennas are facing the sun.

TRANSIENT SIGNAL PROPAGATION IN DISPERSIVE MEDIA: Studies of propagation of transient signals in dispersive media dates back to the early years of this century. Following Einstein's publication of his special theory of relativity, concern arose over the fact that in regions of anomalous dispersion the group velocity is greater than the free-space velocity of light. Since it was believed that the group velocity was the velocity at which energy is transported by the wave; this condition of anomalous dispersion appeared to violate Einstein's theory.

This paradox was correctly explained by Sommerfeld (1914) who showed that the very first part of a signal, called the signal wavefront, arrives at a given point with the velocity of light. Sommerfeld's solution is valid for only a short time after the arrival of the signal wavefront. By using a saddlepoint method of integration, Brillouin (1914) found solutions which are valid in a certain time interval following the Sommerfeld region. The signal in this region is called a precursor since it precedes the arrival of the main signal. The standard saddlepoint method of integration cannot be used in this region of the main signal since the saddlepoint is approaching a pole in the complex plane. Methods for appropriately modifying the saddlepoint method under these conditions have been developed. These

techniques have been used to describe transient propagation in acoustic waveguides, which have the same dispersion equation as a lossless isotropic plasma. Electromagnetic waveguides also have the same dispersion equation, and the saddlepoint method of integration has been applied to these problems.

The solutions discussed so far are approximate solutions that are valid only after the signal has propagated a long distance through the dispersive media. Work in this Laboratory has resulted in the development of more general solutions, valid for arbitrary signals which propagate only a short distance through the plasma. In addition, a detailed study has been made of the solution after long distance propagation in the dispersive medium. This work has important application to the problem of predicting the effect of the reentry plasma on an information-carrying signal.



Plasmas influence radio waves in many ways. This chart shows influences of a cold isotropic plasma on phase velocity and group velocity of a signal.

GENERAL THEORY OF EFFECTIVE PARAMETERS: A vast literature has resulted from studies of electromagnetic wave propagation through plasmas. The foundation of these studies is a simplified model in which the electron-neutral collision frequency is assumed to be independent of the electron speed. Based on this model, a large number of curves have geen generated which give the ele tromagnetic propagation constants in terms of a constant electron density and a constant collision frequency for momentum transfer. Such curves can be found, for example, in books on plasma diagnostics and ionospheric propagation. But these curves are not directly applicable when the collision frequency is a function of the electron speed—and this is generally the case.

A rather intense effort at the Laboratory is centered on this difficulty. The goal of this effort is a more complete theory which includes the effects of velocity dependent collision frequencies, and thus a new expression for plasma conductivity. Since the propagation constants will be known once the real and imaginary parts of the conductivity are known, it is clear that any *two* parameters, which are related to the real and imaginary parts of the conductivity, can be used to characterize the plasma.

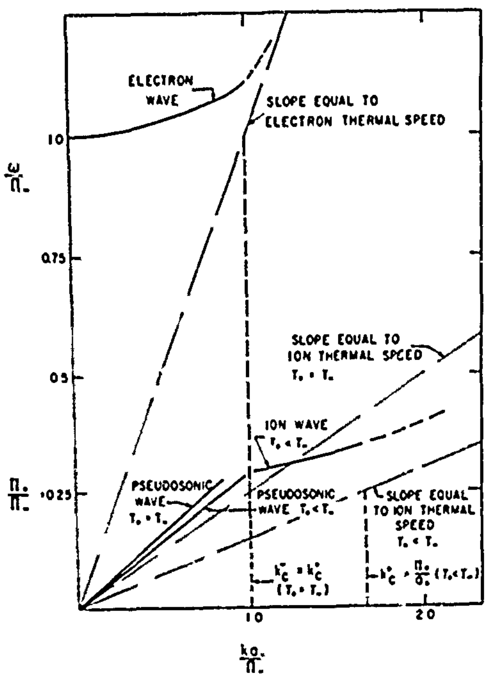
From the point of view of using existing experimental curves of propagation constants versus plasma parameters, it is useful to define an effective collision frequency and an effective plasma frequency. With such a definition of parameters, the electron density, plasma frequency and collision frequency in the experimental curves can be simply interpreted as effective parameters.

These effective parameters have now been generalized to include the characteristic modes in magnetoplasmas. They

were also known to be related to the Fourier sine and cosine transforms of a new collisional response function which is a measure of the momentum relaxation properties of the electron distribution. It is possible to construct an expression for the conductivity, once the response function has been determined directly as a function of time. Curves of the effective parameters have been calculated for the case of various power law dependences of the collision frequency on electron velocity. These effective parameters can also be useful in determining the power law dependence of a gas at room temperature by microwave methods. In addition, the case of the coupling of two different power law variations of the collision frequency has been considered.

For a magnetoplasma in a strong AC electric field, where nonlinear effects are important, it is possible to derive an expression for the isotropic part of the electron distribution function that depends upon the polarization and intensity of the AC field. It has been shown that the applicability of a constant collision frequency model of wave propagation in magnetoplasmas, in the linear case, may be extended to include velocity dependent collisions by introducing an effective collision frequency and an effective plasma frequency. In a strong AC electric field, in addition to being functions of signal frequency and the type of power law dependence of the collision frequency on electron velocity, the effective plasma parameters are also functions of ellipticity and intensity of the AC field. Curves have been obtained of the effective parameters as a function of normalized frequency, normalized field strength and dependence of collision frequency on electron velocity for the case where only mixed modes are present in the magnetoplasma.

NONLINEAR ELECTROMAGNETIC WAVE PROPAGATION IN PLASMAS: The conventional treatment of electromagnetic wave propagation in plasmas proceeds from a set of linearized equations that describe the interaction of the electromagnetic field with the plasma medium. Such an approach is valid for signals whose amplitude is sufficiently weak so as not to perturb the equation of state of the plasma. However, in the case of plasma-coated antennas located on hypersonic reentry vehicles, the power level of signals transmitted through the reentry plasma sheath may not be increased indefinitely because antenna near fields perturb the degree of ionization of the plasma. This limits the power level of the transmitted signal. In this case, a small signal theory as described by a set of linearized equations is not appropriate. There are other practical instances where a small signal theory is not appropriate, such as in the case of Luxembourg type experiments where ground based transmitters propagate rf waves of sufficient intensity to alter the effective collision frequency and/or electron density in the ionosphere. If the power level of an rf field is sufficiently high, the following quantities can be changed in a partially ionized plasma: the form of the electron velocity distribution function, the electron temperature (or width of the distribution function), the electron density, the steepness of the electron temperature gradients, and the steepness of the electron density gradients. These changes imply that all the transport coefficients, such as the thermal conductivity, the DC electrical conductivity, the AC electrical conductivity and the particle diffusion coefficient are all functions of the perturbing rf field amplitude. The changes in these transport coefficients will result in an alteration of the propagation characteristics of the rf wave.



The analysis of waves propagating in a plasma presents the researcher with a task of immense complexity. This chart illustrates several of the many types of waves to be considered.

This particular class of nonlinear interactions is characterized by the fact that part of the electromagnetic field energy is deposited into the plasma medium, resulting in a change in the macroscopic quantities: electron temperature, electron number density and effective collision frequency. Since the propagation characteristics of an electromagnetic wave depend upon the effective dielectric constant of the plasma, which is a function of electron temperature, electron density and collision frequency, a change in these macroscopic quantities will alter the pattern of electromagnetic energy deposition into the medium.

The analysis of the problem has produced many interesting results. For instance, it has been shown that the boundaries defining plasma media can be altered in such a way that an initial electron density profile will appear to move toward the radiating source.

This time-dependent nonlinear analysis has been extended to include the effect of a DC magnetic field which renders the plasma anisotropic to electromagnetic wave propagation. The DC magnetic field is parallel to the electron density gradients and causes a transverse elliptically polarized incident wave (or even a linearly polarized wave) to split into two distinct modes, a right-hand circularly polarized and a left-hand circularly polarized wave. The right-hand and left-hand modes are coupled through an energy balance equation which governs the electron temperature. The value of the electron temperature as a function of time and space depends upon the power density in both right-hand and left-hand modes.

Another class of problems involves the steady-state response of plasmas subjected to intense rf fields. The steady-state nonlinear response of an inhomogeneous plasma, confined in a rectangular slab, and subjected to an rf plane wave, has been considered. The plasma is composed of the constituents of high temperature air corresponding to the chemical composition behind a strong shock wave. The slab geometry is a good approximation to the reentry plasma sheath when the wavelength of the emitted radiation is much less than the radius of curvature of the vehicle body at the antenna location.

For each point in the slab the energy balance equation is solved numerically and the steady-state electron temperature obtained as a function of energy input flux. The curve obtained exhibits a hysteresis effect. For a certain range of values of input energy flux, two steady-state values of the temperature can exist. That which actually exists in

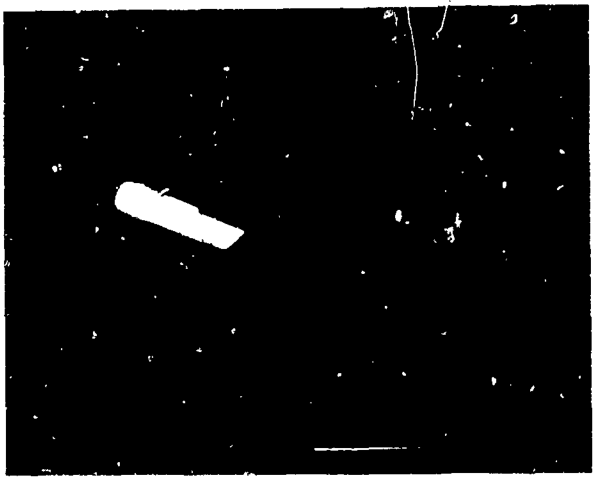
a particular case depends upon the previous history of the system.

DIAGNOSTIC INSTRUMENTATION: The foregoing theoretical work is augmented by complementary Laboratory measurements. Instrumentation and facilities have been designed or accrued for these experiments. Three instruments are noted below.

At pressures above a few torr, a pressure region commonly encountered in plasma activities, conventional manometric (pressure measuring) devices, are not compatible with the requirements of ultrahigh vacuum technology. To overcome this difficulty, a novel interferometric manometer, useful in the pressure range of ten torr and above, was developed. This device, based upon the use of a Michelson interferometer to monitor the change of refractive index and hence pressure, is simple, bakeable and noncontaminating. Lack of moving parts, achieved by the use of optical coupling, permits response to rapid changes of pressure.

Mass spectroscopic facilities capable of monitoring the ionic species present in gas discharges are being developed. An omegatron spectrometer system useful in the range of 1 to 40 AMU (Atomic Mass Units) has illustrated the importance of the rapid decomposition of molecular gases under conditions commonly employed in the production of plasma discharges. A more sophisticated quadrupole mass spectrometer will be employed to determine the composition of plasma over a mass range extending to 200 AMU. With appropriate instrumentation, this facility will permit the measurement of mobilities and lifetimes of various plasma components.

A DC arc-jet facility has been constructed and operated at atmospheric and reduced pressures. Stable operation over long periods of time has been achieved in the micron pressure range with argon and nitrogen gases. A Laval expansion nozzle assembly is capable of longitudinal travel so that a variety of measurements along the plasma stream can be made.



This DC arc jet facility is used at AFCRL to investigate collision processes in gases at temperatures normally encountered behind a shock wave such as that surrounding a nose cone reentering the atmosphere. The jet is fired in the glass bubble seen in the center of the photo below.

LABORATORY EXPERIMENTS: Initial use of the arc-jet facility noted above involves the measurement of the electron energy relaxation time in high temperature (5000 degrees K) gases. The jet is permitted to impinge upon a hole in the wall of a water-cooled S-band waveguide section. A column of hot gas, free of the container walls, is produced within the waveguide. Microwave radiation at S-band frequencies is then used to selectively heat the electrons in the test gas column. A second S-band signal of different frequency and much lower power level is used to measure the effective collisional cross section of the hot gases as a function of electron temperature. This experiment essentially employs a cross-modulation or "Luxembourg effect" diagnostic technique. Information on inelastic electron-neutral collision processes in gases at temperatures normally encountered behind a strong shock wave can thereby be gathered.

The nonlinear behavior of ion fed gases irradiated by long-duration, high power, microwave pulses is being studied in an effort to corroborate certain theoretical calculations made at AFCRL. The proper combination of electron density distribution and microwave pulse can produce an over-dense or strongly attenuating front which, as noted above, travels toward the source of radiation. This moving front effectively blocks the microwave energy and forms a shield through which little signal power will pass. This phenomenon has been produced in both active and decaying discharges in the Laboratory over a wide range of conditions. Electron density distributions, produced by pulsed rf or DC techniques, have been irradiated by x-band pulses of two millisecond duration and up to 25 watts/cm^2. Numerous diagnostic techniques, including microwave interferometry, electro-acoustic probing, and photometry, have been used to characterize the moving shield. Velocities are characteristically in the sonic range, and the front moves throughout the duration of the applied pulse. Continuing experiments are designed to yield more specific information as to the shape of the electron density profile, propagation characteristics and the effects of magnetic fields.

A study of the variation of the elastic collision cross section with electron energy is being conducted in Xenon gas. Xenon, together with certain other rare gases, exhibits an anomalously small elastic collision cross section (the Ramsauer minimum) for certain electron energies. In Xenon, this minimum occurs at about 4500 degrees K. Thus, electrons being heated from room temperature (300 degrees K) display a decreasing collision cross section with increasing temperature. This behavior is comparable to the Coulomb cross section dependence at a constant electron density. Coulomb type collisions are predominant in the highly ionized media often encountered in Air Force applications. Thus, the development of sophisticated diagnostic techniques for the Xenon measurements should be equally useful with the similar Coulomb type dependency.

Microwave cross-modulation techniques and a transient microwave radiometer are used for the Xenon measurements. The radiometer is capable of measuring a minimum radiation temperature of 600 degrees K with one microsecond time resolution.

The rate at which the electrons of an ionized medium give up their energy to the surrounding gas is being measured in several atmospheric gases. Studies of nitrogen and oxygen parent gases have been completed. Interest has now

focused upon nitric oxide which, although a minority gas in atmospheric composition, was suspected to play a significant role due to its abnormally high electron collision cross section. The technique of gyromodulation of two microwave signals in a decaying plasma is used. The plasma is placed within a magnetic field so that conditions of electron cyclotron resonance at about four GHz are realized.

The applied electromagnetic energy is resonantly absorbed and affects the plasma energy content. This, in turn, alters the electron production and loss processes. These changes may be monitored by a second, low power, probing microwave signal of different frequency. Experiments were conducted in nitric oxide plasmas in the pressure range of 0.05 to one torr. It was found that the fractional energy loss of an electron per collision in nitric oxide is an order of magnitude larger than that in nitrogen, and two orders of magnitude greater than oxygen. These results indicate that consideration of the contribution of nitric oxide in atmospheric plasma interactions with electromagnetic energy is indeed necessary.

Of further interest was the appearance of helical instabilities in the magnetoplasmas formed in atmospheric gases. This type of discharge instability is a probable result of large gradients in electron density and/or electron temperatures created by rapid inhomogeneous heating. Similar instabilities have been previously noted in rare gases at the University of Illinois. Such instabilities can produce enhanced plasma diffusion across magnetic field lines and result in unexpectedly large particle losses during microwave diagnostic procedures and other magnetic plasma containment operations.

Plasmas are produced in long discharge tubes located in air core solenoids such as that shown above. The magnetic field concentrates the charged particles, permitting measurements to be made of attachment and recombination coefficients and electron energy relaxation rates.

MILLIMETER WAVE PROPAGATION AND ENVIRONMENT RESEARCH

The Laboratory's millimeter wave research program centers about its 29-foot millimeter wave antenna (15 to 100 GHz) located at the Prospect Hill Radio Observatory, Waltham, Mass. This research has two objectives. The first is to investigate the limitations imposed by the atmosphere on propagation of electromagnetic energy at millimeter wavelengths. Potential applications are in the areas of communications and high resolution radar. The second is to use the propagated wave as a diagnostic tool to obtain information on lower atmospheric structure and to investigate the gross surface properties of the sun, moon and near planets.

Strongly motivating this research is a requirement for high data rate and broadband earth-to-space communications channels. The longer wavelength

Millimeter wave propagation research is conducted at AFCRL using this radio telescope which operates at frequencies between 15 and 100 GHz.

region of the electromagnetic spectrum is already overcrowded and the usable spectrum will have to be extended into the millimeter wave region out of necessity. In addition, small wavelengths mean high gain, high resolution, compact antennas. All these features are obviously desirable in space vehicle instrumentation.

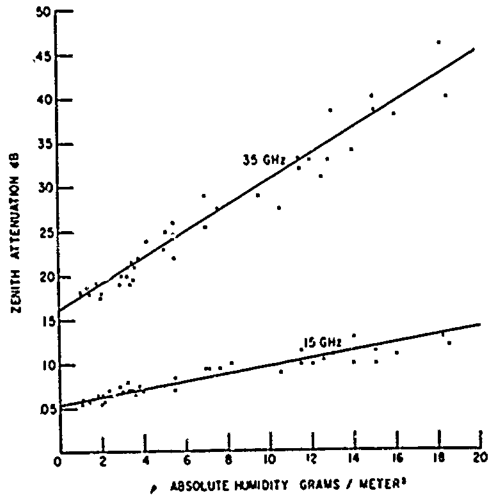
Further advantage relates to the communications "blackout" experienced by vehicles during reentry—a problem discussed in the previous section. Theoretically, such a "blackout" is not possible at millimeter wavelengths because they are lower than the corresponding plasma cutoff wavelength for most expected vehicle trajectories.

The inherently high resolution of millimeter wavelength systems can lead to the development of high precision radar systems for tracking, guidance and mapping. As smaller wavelengths are used, however, the basic physics of the situation give rise to certain antenna problems. One of these is that the ultimate size of the antenna aperture is limited by mechanical tolerance. Contouring of the collecting surface must approach optical tolerances to overcome aberrations. The system is also "atmosphere" limited. The effect of the atmosphere is to make a coherent wave only partially coherent thereby degrading the performance of the antenna.

This particular degrading effect—that is, the strong interaction between the lower atmosphere and millimeter waves—can be used to advantage. It may be possible to obtain information on clear air turbulence, atmospheric temperature, pressure, water vapor profiles and cloud composition by using short wavelength radar and radiometric sensors.

In addition, the intensity of radiation emitted by a thermal radiator is inversely proportional to the wavelength squared (in the Rayleigh-Jeans region of approximation) so that higher power signals are received at the short, millimeter wavelengths than at the longer wavelengths. As a result, it may be possible, with millimeter systems, to obtain information on the gross surface properties of the moon and near-in planets.

ATMOSPHERIC ATTENUATION: Using the sun as a source and radiometers as detectors, the Laboratory has measured the atmospheric attenuation of millimeter energy as a function of zenith angle and various meteorological conditions over a period of approximately one year. The radiometers were designed to operate at frequencies of 15 and 35 GHz. Since the energy emitted by the whole sun is relatively constant as a function of time at these frequencies, the attenuation is simply equal to the decrease in received signal.



Under clear sky conditions, atmospheric attenuation at millimeter wavelengths is well correlated with absolute humidity at frequencies of 15 and 35 GHz.

Clear sky attenuations were found to be well correlated with absolute humidity and were also found to increase proportionally with the secant of the zenith angle up to 85 degrees (five degrees above the horizon). This agrees very well with theory since only the lower 20 kilometers of the atmosphere attenuates millimeter waves and the total pathlength through that layer is proportional to the secant of the zenith angle. Attenuation increased slightly during unsettled conditions and became quite large during heavy rainfall. Because consistent and complete data during varying conditions of precipitation are lacking, the Laboratory plans to continue these measurements in a location —possibly Hawaii—where precipitation is frequent and varies in intensity. It may be possible to show that atmospheric attentuation during heavy rainfall is not prohibitive if propagation paths close to zenith are utilized.

Finally, NASA is presently planning to launch an experimental millimeter wave communications satellite in late 1968. The AFCRL 29-foot millimeter wave antenna has been selected as a ground station for this program.

SOLAR INVESTIGATION: Most solar observations have been conducted at either the optical or the longer radio wavelengths. During the reporting period, extensive solar observations were made at millimeter wavelengths using AFCRL's 29-foot radio telescope. The observations are a part of the larger AFCRL program devoted to the forecasting of solar proton showers (see Chapter III). Millimeter wave observations fill an essential gap in solar observational data.

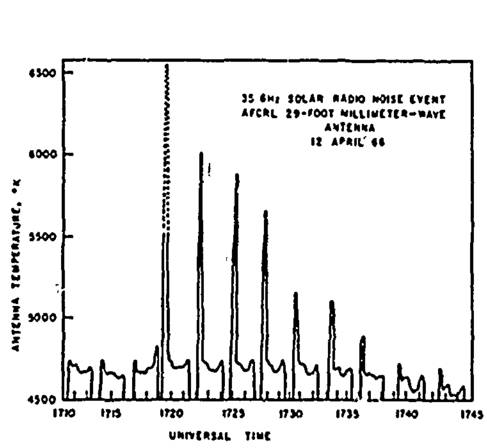
The sun can be considered to be a plasma having associated with it a plasma cutoff wavelength. Therefore, the depth of penetration of an electromagnetic wave or conversely the depth from which electromagnetic radiation is received from the sun is a function of

This contour map shows the relative temperature distribution of the sun at 35 GHz on July 11, 1966, 1700 UT. The zero level contour corresponds to an antenna temperature of approximately 4800 degrees K.

wavelength. Radiation at optical wavelengths originates from the photosphere (the apparent solar surface); that at centimeter wavelengths, from the high chromosphere (8–10,000 km above the photosphere) and that from the longer wavelengths from the corona (the outermost section of the sun). Radiation at millimeter wavelengths originates from a region above the photosphere about half way into the chromosphere, the region in which flares are believed to have their origin.

Solar observations have been conducted since April 1966 using the AFCRL 29-foot millimeter wave antenna. This precision instrument, at a wavelength of 8.6 millimeters (35 GHz), has a half-power beamwidth of 4.2 minutes of arc or a projected area approximately 1/60 that of the sun. A contour map of the temperature distribution over the solar disc is obtained by an automatic scanning program generating, in discrete steps, a rastertype scan over the disc.

The most obvious feature of these contour plots is the existence of warm and cool regions moving over the solar disc corresponding to the slowly varying component of the 8.6 millimeter solar radiation. The warm regions correspond closely to the plage or apparently warm regions seen in H_a (hydrogen alpha) light. Typically warm regions, present nearly all the time on the disc, exhibit core temperatures 200 degrees K above the background. On occasion these regions were observed to remain as much as 800 degrees K above the background for an entire day. The presence of large cool regions, probably defining the level of the basic component of the radiation, appear to wander around. The lower level contours show very little similarity after 48 hours. This is in contrast to the motion of the warmer areas which migrate consistently in accordance with the motion of the active regions on the disc.



The above record of a series of drift measurements of the sun obtained with the AFCRL 29-foot antenna is believed to be the first high resolution observations of a millimeter wave burst. The record is associated with the solar flare of April 12, 1966.

While carrying out this program, Laboratory scientists observed the solar flare of 12 April 1966. This is believed to be the first high resolution observation of a millimeter burst to date. Repeated drift scans were made of the sun, at five minute intervals, each scan passing through the center of the disc. A curious feature that occurred at 1719 Universal Time was a sharp increase in the received signal—an increase by at least 50 percent over the previous scan. The signal then decreased slowly to its normal level in the following 30 minutes. Investigation of the optical characteristics of the event indicated that a flare of importance 1 occurred on the west limb of the sun from 1715 to 1749 UT. Additional radio data from facilities engaged in monitoring solar flux levels indicated that a 2 to 3 minute duration burst occurred from 1718 to 1720 UT at both 8800 and 4995 MHz, while no significant flux increase was seen on the lower frequencies of 606, 1415 and 2695 MHz. Several similar

bursts have been recorded since that time.

The conclusions from the data reported here are that slightly enhanced emission at 8.6 millimeters originates from chromospheric layers above the plage regions, and that the millimeter burst occurs over the optically active region and has a duration which appears identical to the associated optical event. From this demonstration that the millimeter wave burst corresponds closely in both time and location with the optical flare event, arises the possibility that observations of millimeter wave radiation from active centers may reveal a characteristic signature which may be of significant value in forecasting applications.

MICROWAVE ACOUSTICS

Microwave acoustics encompasses research in the generation, propagation, amplification, control and detection of microwave energy in the form of acoustic and other slowly propagating waves in solids. Early work in this field was motivated by the desire for compact, solid state microwave delay lines. Potential applications have now expanded to include high density memory, signal processing, pulse compression, frequency conversion and microwave integrated circuits.

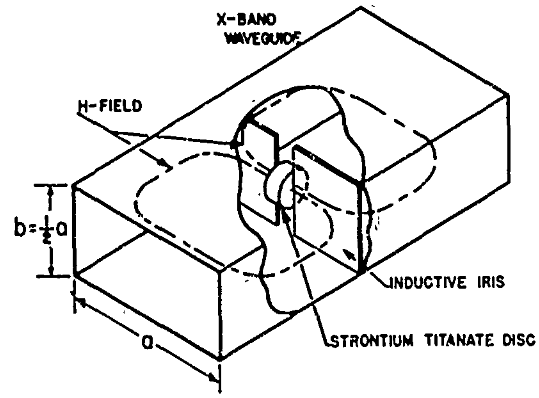
The research itself, however, is several steps removed from specific devices. It consists of the understanding of acoustic waves (phonons), spin waves (magnons) and in the interaction of these waves with themselves, each other and with other forms of energy including coherent light, drifting carriers and microwave electromagnetic fields. In addition to in-house research, contractual research includes basic studies in the properties of acoustic and magnetic materials, the nature of optical-acoustic-magnetic interactions and research aimed toward the development of microwave acoustic components such as high-efficiency, broadband transducers, acoustic resonators and other circuit elements.

The Microwave Physics Laboratory sponsored a microwave acoustics symposium in October 1965 aimed at bringing cohesiveness and direction to the many independent studies in this new and growing field.

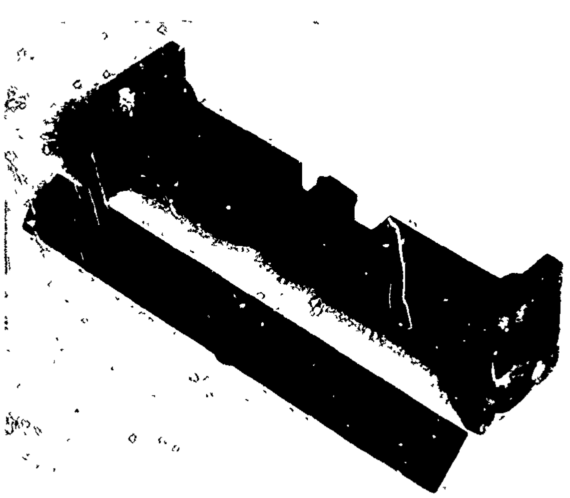
MAGNETIC DEVICES: Ferrimagnetic single crystals, of which yttrium iron garnet is the classic example—and still the most useful—are widely employed in microwave devices. These devices include isolators, filters, parametric amplifiers, switches, circulators, modulators, phase shifters and delay lines. All of them rely on one of two basic macroscopic phenomena for their operation. One phenomenon is a spatially uniform magnetic mode, and the other a propagating magnetic mode. An interesting feature of these propagating modes is that, in principle, the mode group velocity can be controlled with a magnetic biasing field over the entire range from zero to the velocity of electromagnetic waves.

Another fundamental mechanism under investigation is that of propagating magnetoacoustic modes. Areas of investigation include the modeling of these modes in terms of coupled transmission line theory, the use of thin ferromagnetic films as transducers and the use of high dielectric materials as coupling structures between the electromagnetic and magnetoacoustic modes.

Work is in progress on a new microwave phonon spectrometer. The spectrometer measures both acoustic absorption and acoustic wavelength as a func-



A new type of tunable band pass filter with insertion losses of less than 2 db with an output spectrum of only a few percent of the center frequency is shown in schematic above. The filter, a model of which is shown below, can be constructed for any desired frequency from 1 to 12 GHz and for either fixed frequency or tunable operation.



tion of such external parameters as applied magnetic field or temperature. Measurement of the magnetic field variation of the phonon wavelength with the spectrometer will provide a new method of studying the important magnetoelastic interaction in ferromagnetics. This interaction constitutes the basic mechanism in current microwave variable delay devices. The first materials to be studied with the new technique will be the single crystal nickel metal platelets of extremely high chemical and structural purity which are grown by General Electric Research and Development Laboratories. The magnetoelastic interaction, anticipated to be a strong one, has not yet been seen in these materials.

PIEZOELECTRIC MEDIA: The square of a sinusoidally varying function contains both a second harmonic and a static component. Previous experiments at AFCRL dealing with nonlinear microwave acoustics (microwave phonons) have detected the second harmonic. A recent accomplishment has been the detection of the static component, which is the equivalent of rectifying microwave energy. The apparatus used is shown in an accompanying figure.

Since the desired output voltage is largest when the optically polished quartz discs are excited at an overtone acoustic resonance frequency, the cavity is tuned to an odd multiple of the fundamental acoustic frequency of the disc. The quartz disc, in contrast to the detecting semiconducting diode, is almost "burnout" proof. Its power handling capabilities are mainly limited by electrical breakdown across the electrodes of the reentrant cavity, which occurs only when about 100 watts of microwave power are dissipated in the cavity.

At acoustic resonance, the dominant nonlinearity is the strain dependence of the piezoelectric constant of the disc. A theoretical analysis shows, however, that while off resonance, the magnitude of the voltage was produced mainly by radiation pressure, or Maxwell-Faraday stress.

The frequency dependence of the output is related to the surface quality of

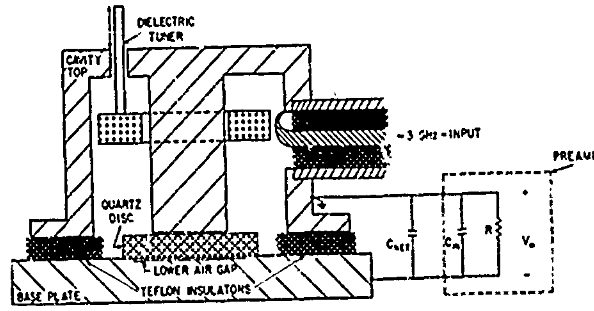
the quartz. Discs, with a surface roughness much greater than the sonic wavelength of the phonons, produce no observable acoustic resonance. This property is useful for broadband applications. The experiment has resulted in a square law detector that exhibits either high Q or an essentially flat frequency response, depending on surface roughness of the disc.

The mixing of microwave energy by nonlinearities in the excitation of the disc has been observed. A bandwidth of the order of ten kHz makes such a piezoelectric mixer attractive since it also operates at power levels higher than is now possible with presently available semiconducting diodes. These mixers may also be of use in high power radars where elaborate switches must be used to prevent burnout of the semiconducting mixers.

DIELECTRIC RESONATORS AND FILTERS: Recent advances in the consistent production of high quality, high dielectric, low-loss crystals have made practicable the dielectric resonator. AFCRL's Solid State Sciences Laboratory has provided most of the high purity rutile and strontium titanate crystals used in this Laboratory. Although the dielectric constant of such materials is highly dependent on temperature, past efforts have shown that the temperature, hence the frequency, of such resonators can be stabilized even while absorbing up to two watts of CW power.

A practical way of providing frequency tuning in dielectric resonators has recently been developed at AFCRL. The method hinges on mechanically separating two or more resonators. Tuning ranges in excess of 20 percent of the resonator resonant frequency have been obtained.

The high absorption and rejection characteristics of dielectric resonators



AFCRL's resonant cavity device for rectifying microwave energy uses a quartz disk which functions as a square law detector.

made their use as band pass-band stop filters very attractive. For band stop applications, only proper positioning of a resonator crystal of the correct geometry in the waveguide is required. The purer the crystal, the lower the losses in the crystal and the narrower the filter's bandwidth. If band pass applications are desired, the crystal is placed into an inductive iris in the waveguide. Bandwidths from 20 to 40 MHz have been achieved at X and C bands and insertion losses of less than two db were measured. The width and thickness of the iris determine the bandwidth and losses respectively.

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Early in 1967, several of the world's leading gravity research scientists met at AFCRL to discuss plans for the world gravity network.

IX Terrestrial Sciences Laboratory

The Terrestrial Sciences Laboratory conducts research in seismology, geology, gravity and geodesy. These four areas have a common requirement for field surveys that are worldwide in extent. The four areas of study have a further common feature in that they all require the design and development of new sensors, instrumentation and measurement techniques. Such design and development is an inseparable part of the Laboratory's efforts in each of the four areas and is often far more demanding of talent than the job of conducting the surveys themselves.

Still more demanding of skills are interpreting data, formulating mathematical models, and evolving a theoretical understanding of the phenomena under study. And these, in turn, can lead to the development of even more effective instruments for gathering more precise data. While this lock-step progress is a feature of most empirical research, it is found to a marked degree in the program of the Terrestrial Sciences Laboratory.

A large part of the seismology program was undertaken at the request of the DoD Advanced Research Projects Agency and was initially concerned solely with the remote detection by seismic means of underground nuclear detonations under the VELA UNIFORM program. The seismic program has been broadened and diversified far beyond the original goals. Development of ocean bottom seismometers, and their testing in the Pacific, was a strong feature of the program at the beginning of the reporting period in 1965, but by June 1967,

AFCRL's work had been completed and the ocean bottom seismometers have been placed in service by another agency. Expanded during the period was work within the Laboratory on materials testing. In these tests, materials making up the earth's crust are subjected to high temperatures, pressures and strains to gain a better understanding of the catastrophic releases deep within the earth that are manifested as earthquakes.

In geology, the Laboratory continued its study of terrain features over the earth's surface that are significant in Air Force operations. Of current interest are broad flat areas (such as dry lake beds) that might serve as natural landing fields for aircraft or space vehicles. A new analytical laboratory was established in which various crustal materials are given x-ray, spectroscopic and chemical analyses. Also, new instrumentation was installed on a C-130 aircraft for airborne geologic surveys, a number of which were undertaken during the period.

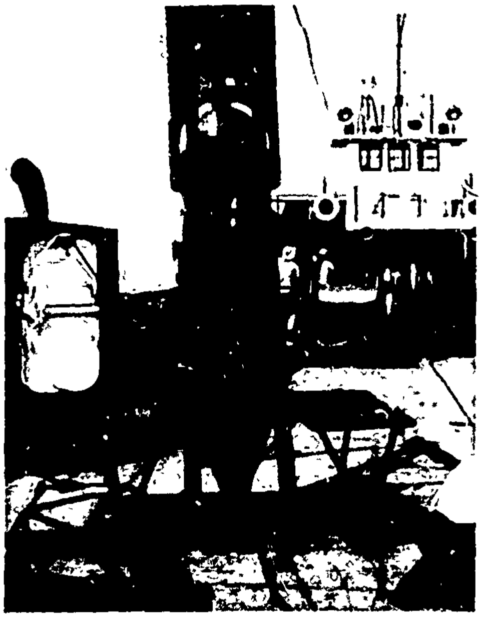
The Laboratory's gravity research program is related to Air Force needs for missile and satellite guidance accuracy. The Laboratory is a major participant in the Worldwide Gravity Standardization Program, an international program that was just getting underway at the beginning of the period, but which is now well-established with the basic framework of standardization and calibration sites and lines almost complete. In addition to ground surveys, airborne surveys were made with instrumentation aboard AFCRL's KC-135 aircraft. The most important new instrument developed was a falling-body laser absolute gravity apparatus. At the conclusion of the period, the instrument was ready for its first scientific use. This instrument promises to be one of the more significant new gravity measuring devices developed during the past ten years.

AFCRL's work in geodesy is concentrated on gaining more precise knowledge of the size and shape of the earth, and distance between points on the earth's surface. Satellites, which five years ago were an exciting new tool of unproven potential, have now become a basic and routine tool of the geodesist. A new program was initiated devoted to the use of balloons in surveys of middle distances of between about 100 and 200 km—distances exceeding the visibility level for conventional ground surveys, and too short for precise geodetic satellite measurements.

SEISMOLOGY

Seismic research at AFCRL, historically, has been directed almost exclusively at problems of detection and identification of underground nuclear explosions as part of the Defense Department's Project VELA UNIFORM. With the decreased emphasis on the VELA UNIFORM program, AFCRL's effort to establish the feasibility of specific seismic systems has lessened, and there has been a corresponding increase in more general seismological research. This research is nevertheless strongly flavored by original goals of detecting underground nuclear explosions. The Laboratory's seismic research programs can be grouped under several headings: source characterization, elastic wave propagation, source identification, rock mechanics, anelastic wave propagation, and environmental seismic noise.

SOURCE CHARACTERIZATION: If the seismic source (explosion or earthquake) is more thoroughly understood, success



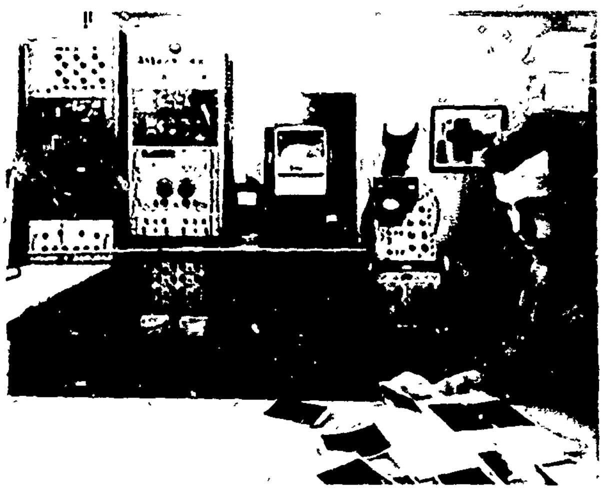
AFCRL, under a program that was largely terminated during the reporting period, placed underwater seismometers such as that shown above at a number of locations in the Pacific Ocean.

in isolating and identifying unique signal characteristics radiating from each source should be enhanced. This hypothesis is being pursued through theoretical work with the goal of developing a theory applicable to seismic energy radiating from both faults and underground nuclear explosions.

Little is known about the actual spatial and temporal distributions of displacements on a moving fault. But rather plausible assumptions about certain average properties of the fault motion have permitted calculations of the total radiated energy and its spectral distribution in a statistical sense. Using available, although limited, data on the dimensions of faults in relation to earthquake magnitude, theoretical earthquake energy spectra as a function of magnitude have been calculated. These theoretical spectra agree qualitatively with meager information that was available on the spectral distribution of the energy of actual earthquakes.

Experimental observations of ground motion measured in the elastic region near underground nuclear explosions in several different media have been fitted quite closely to a family of analytic functions. By using these functions it has been possible to calculate the total energy of the elastic wave radiation and its frequency spectrum. The calculations provide a useful basis for comparison between the source energy spectra of underground nuclear explosions and earthquakes.

Horizontally polarized shear waves (SH) that show up in data recorded from distant underground nuclear explosions greatly complicate the problem of explosion discrimination. Available seismic evidence suggests that mode conversion along the travel path and near source inhomogeneities do not adequately explain the anomalous SH and Love waves. The explanation may lie in



Oscillograms of seismic waves show characteristics of these waves as a function of the material through which they propagate.

the tectonic strain release caused by the explosion. To help resolve the problem, an AFCRL seismic modeling program was initiated to examine the radiation from explosions detonated in biaxially prestressed and unstressed static fields under laboratory conditions. The propagating wave, initiated by the explosion of a length of mild detonating fuze, has been recorded in the near-source region by means of the photoelastic effect (clearly visible in clear plastic) and an ultrahigh speed camera, and in the far field by means of strain gages.

ELASTIC WAVE PROPAGATION: After a seismic wave has propagated through the earth, the information contained on a seismogram consists mostly of the characteristics of the earth with little residual information on the characteristics of the source. Yet it is the source information which is of primary interest for most military purposes. Most of the data on the seismogram must, therefore, be corrected out, using appropriate propagation theories, in order to obtain source information.

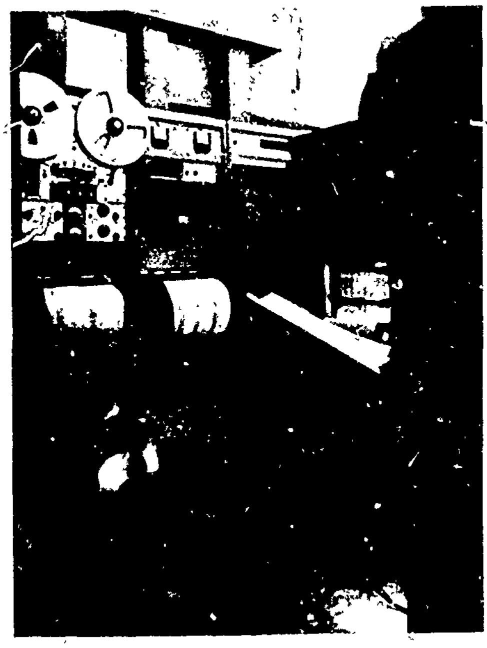
Recent work involved a study of the P wave. The P wave travels from the source to the receiver along a path lying entirely in the crust. (P waves, by comparison, penetrate the mantle and travel through the earth.) Because the earth's crust is multi-layered, however, the P experiences multiple reflections within the crust, such that energy contributions arriving simultaneously at the detector have traveled over many different paths within the crust.

In order to use P to glean information about the source, it is necessary to know the attenuation of this wave as a function of frequency. Previous workers had assumed that the attenuation of P was primarily due to absorption of the energy of the wave by the material of the crust as the wave passed through it. Under this assumption, the leakage of P from the crustal wave-guide into the mantle is ignored. AFCRL scientists have evaluated this assumption, showing that the leakage may be as important a contributor to the losses as the absorption, and have developed a theory to quantitatively account for both effects.

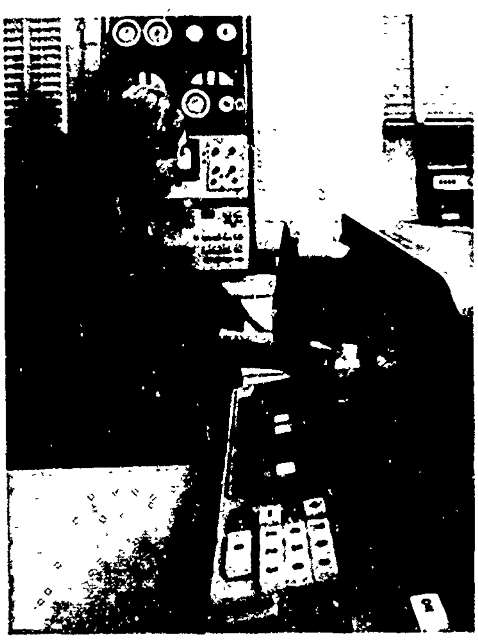
SOURCE IDENTIFICATION: If one knows that the source of a seismic disturbance is deep beneath the surface of the earth, then a sizable proportion of all seismic events can be dismissed as naturally occurring. Likewise, if the event can be assigned to a general geographical region where no one is likely to conduct underground nuclear tests, this event can also be considered natural. Laboratory scientists, and scientists working under AFCRL-sponsored efforts, have identified key parameters, and the number of parameters originally considered as potentially suitable for discrimination has been reduced.

The key parameters are primarily those associated with measurements of the complexity of the P wave and some phases of later arriving energy. In addition, an entirely new technique has evolved to compute high resolution wave spectra for the detection of very weak aftershock sequences of earthquakes. Statistical classification and pattern recognition applied to known source types have correctly classified a high percentage of events.

A potentially useful diagnostic criterion—the relative excitation of surface waves of earthquakes and underground explosions—has been discovered. The parameter, which is called AR, measures the area of the envelopes of surface waves recorded by three-component, long period instrumentation. Continued evaluation and further refinement of



Since 1961, AFCRL has supported a network of seismic stations in New England. Data from four remote unmanned stations are transmitted automatically to a central processing station at Weston, Mass., where data are recorded (above) and processed (below).



this identification technique has provided additional confirmation of its value as a diagnostic aid.

The effective operation of a seismic detection network will depend to a great extent on determining the hypocenter (geographic location and focal depth) of seismic events. As accuracy in locating the hypocenter improves, more and more events can be removed from the suspicious category. However, local and regional variations in travel times of seismic waves and the failure of conventional methods for determining depths where the source is shallow have made this task difficult. This has led AFCRL to sponsor a number of studies to determine crustal structure and regional travel times. Regions included are New England, the southeastern U. S., the central U. S., northwestern U. S., northwestern Canada, the Alpine region of Europe and northern Europe.

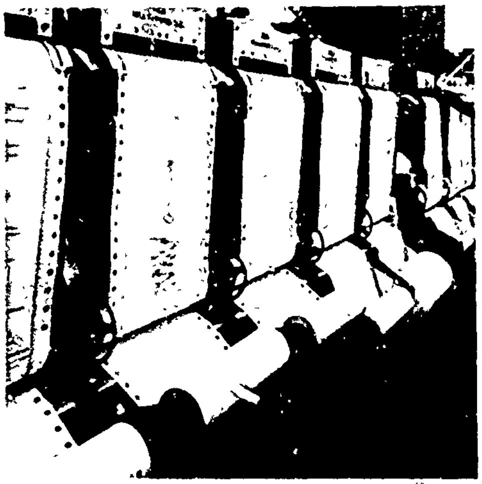
A method for computing focal depth from the frequency spectrum of seismic signals recorded at a single station is under study using calculations of the potentials of up-going and down-going P and S waves on a vertical line through the epicenter. Theoretically, only at the depth of focus should the waveforms of the four potentials start at the same instant. Testing of the method is in progress.

ROCK MECHANICS: During the period, experiments were conducted on a large variety of deep earth minerals and rocks under pressures to 100 kb and temperatures to 1000 degrees C at the AFCRL high-pressure, high-temperature facility using a shear press of unique design. The shear tests are made to learn more about the deformational properties of deep earth materials (actually, their analogs) under geophysically realistic temperatures and pressures simulating depths to 300 km.

Shear tests on serpentinized dunite exhibited extraordinary weakening of otherwise strong silicate mineral when the test temperature was raised above the dehydration temperature of the associated hydrous serpentine. Similar "water weakening" was noted in material associated with hydrous zeolite minerals. Water vapor developed from dehydration resulted in pore pressures of sufficient magnitude to lower effective confining pressure. This decreases strength and ductility to very low values.

In another series of rock deformation tests, shearing of the pyroxene mineral enstatite was found to induce a change of phase and a small but significant change in volume. Calculations have demonstrated that under the influence of shear stresses a volume of enstatite in the deep earth will invert to a smaller and denser polymorph in a few seconds. Since the energy produced by the inversion is sufficiently large to yield seismic energy of large magnitude, the inversion may be considered a possible source mechanism for intermediate and deep-focus earthquakes.

Two new deformation devices, a small shear press and a solid-pressure, constant strain-rate device, are being designed and fabricated under AFCRL contract. When added to the present AFCRL test facility, the devices will permit study of the mechanical properties of earth materials to temperatures of 2000 degrees C, pressures to 150 kb, and strain rates as low as 10^{-8}/sec. This will give AFCRL scientists a capability to simulate environments as deep as 450 km below the surface of the earth. Many seismic phenomena have their origin within this depth range.



Acoustic waves in the atmosphere cause small tremors on the earth's surface which are easily detected by seismometers. The tracings on these machines are acoustic-produced seismic waves from several locations in New England.

ENVIRONMENTAL SEISMIC NOISE: The earth's environmental seismic noise field, in the sense discussed here, consists of all vibrations, however small, detected at the earth's surface. Many of these are naturally occurring microseismic events. But whether they originate from beneath the earth's surface, on the earth's surface (ocean surf and trains) or above the surface (sonic booms of aircraft), all come under the grouping of environmental seismic noise.

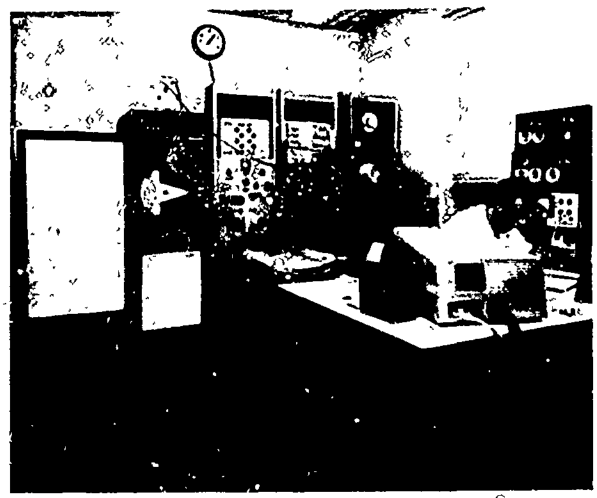
The average magnitude of this noise varies with location. Some places tend to be quiet, others noisy. Many motion-sensitive equipments require a relatively vibration-free environment for proper test and calibration—the testing of sensitive inertial systems for use in guidance systems, optical benches, gyros, laser beam analytical work, and so on. And, of course, the placement of seismic equipment and arrays is governed by the levels of environmental seismic noise likely to be encountered.

AFCRL has initiated a new program around the study of microseismic noise. Part of this program consists of developing equipment for measuring the

noise field at particular locations. In this connection, AFCRL has developed a portable 18-element seismic array for placement in a variety of geometrical configurations in any geographical or topographical environment. The capability to perform rapid higher order statistical analyses on the magnetically recorded data has been established through acquisition of a high-speed statistical analyzer and a general purpose computer capable of handling multiple-channel digital and analog inputs. Such functions as fast search multiple-correlation, convolution, power spectral densities, and so on, can be performed on multiple-channel input data from both on-line and magnetic tape recordings.

Using the portable seismic array, AFCRL is accumulating a magnetic tape library of environmental seismic noises at Air Force bases. The purpose is to determine seismic noise differences between air bases and to evaluate noise field characteristics common to air bases. Computer programs are being developed to identify various aircraft through take-off and landing seismic signatures. Also, programs have been developed to determine the directivity of any given environmental noise field, and to identify its source.

AFCRL has been requested to use the portable seismic array to determine environmental seismic noise levels at selected sites and locations where motion-sensitive equipments are or will be employed. Studies conducted concern the effects of seismic background activity on laser operations, multiple-phased satellite antenna arrays, gravimeter operations and the determination of the long-term noise field at NASA's new Boston Electronic Research Center.



The recording and processing equipment shown here is used to analyze data from AFCRL's portable seismic array.

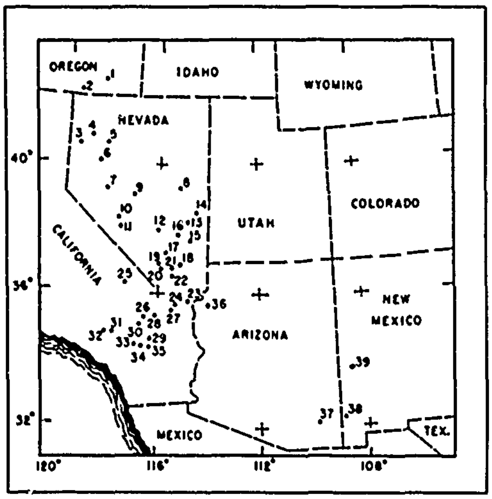
GEOLOGY

The Laboratory's geology research program involves terrain features in all global environments that might be exploited by the Air Force in its defensive, operation and support missions.

The core of the program is the geologic analysis of natural terrain. The program includes the study of the evolutionary and environmental history of regions in order to predict future changes in surface morphology. The program also includes the development of new instruments and techniques for the remote sensing of terrain features.

Much of this research is conducted in the context of Air Force aircraft operations. One purpose is the study of areas over the earth's surface that might serve as natural landing areas for alternate or emergency operations. The instrumentation developed for airborne geologic surveys has also been found to be potentially suitable for certain operations in Southeast Asia, such as the detection of well-camouflaged enemy operations, and for tunnel detection.

Historically, the geology research program of the Laboratory was concentrated in the arctic. During the previ-



The Laboratory's geology program is primarily concerned with terrain that might serve for certain Air Force operations. The dry lake beds designated (by number) on the above map have been of special interest.

ous reporting period, 1963–1965, the effort was focused on terrain features of the southwestern U. S. During the present reporting period, the work became more global, stretching toward the Middle East and the tropics.

Two programs have been greatly augmented. One of these is the establishment of materials analysis facilities to which various kinds of crustal materials are brought for analysis. This research will provide quantitative data on physical properties of a given material under varying degrees of temperature and hydration. The second expanded effort relates to airborne surveys. Equipments developed during the previous reporting period were incorporated in a C-130 aircraft and surveys were made over Middle Eastern countries, tropic regions, Iceland and Greenland. As a sidelight to the Middle Eastern survey, AFCRL was asked by archeologists of the University of Pennsylvania to use the unique instrumentation to survey an area of Italy where they suspected an ancient Greek city might be buried. Previously undetected areas were observed and suggested as future excavation sites.

NATURAL LANDING AREAS: Many natural terrain areas from which Air Force aircraft might operate are found throughout the world. With the development of aircraft with rough-field landing capability, many areas previously dismissed as not important have recaptured the Laboratory's attention. Literally thousands of areas over the earth provide accessible, secure, and inexpensive bases for emergency use. The use of such natural areas depends on the surface loads imposed by the aircraft landing gear in relation to soil characteristics.

Laboratory scientists have studied the behavior of soils under transient, dynamic loads for many years. Mathematical relationships have been derived for the flow of soils as a function of granularity, mineral composition, and packing density. These were then verified in experimental models simulating elastic, viscoelastic, and plastic deformation. Full-scale operational tests with aircraft will be conducted in coming months.

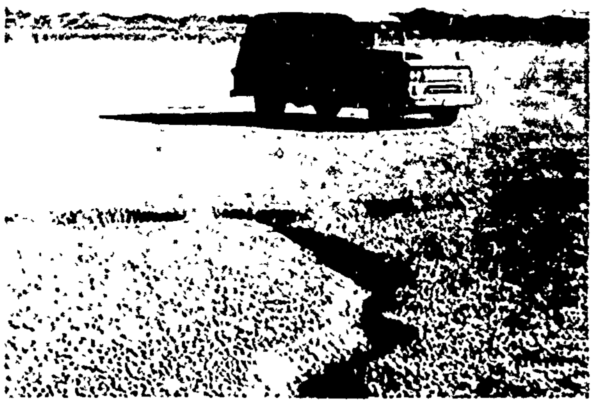
PLAYAS AND LANDFORM ANALYSIS: Playas (dry lake beds), found throughout the arid regions of the world, are perhaps the best of natural landing areas. These flat, hard clay and salt surfaces are typified at the Edwards AFB, Calif. playas and in the Bonneville Salt Flats. For the past several years, Laboratory scientists have investigated the properties of these unique landforms. Most playas are usable throughout the year but occasional flooding or subsurface drainage may temporarily hinder operations. Thus, the change in playa surfaces with time is the subject of current research. Field investigations of such desert basins are concerned with

sedimentation, drainage, and fracture patterns.

For these investigations, many subsurface geophysical techniques are used—gravity, magnetic, seismic, as well as drilling and mineral analysis. Material samples are returned to the AFCRL Laboratory where they are studied for a host of properties by x-ray diffraction, differential thermal analysis, and petrographic and spectrophotometric analysis techniques. A landform study of playas is currently underway to correlate the morphology of U. S. playas with analogous desert regions of the world.

An automated system is being developed to monitor soil strength, moisture properties, and local climatic variables in remote locations. These telemetered data will be used to determine or forecast the usability of a site.

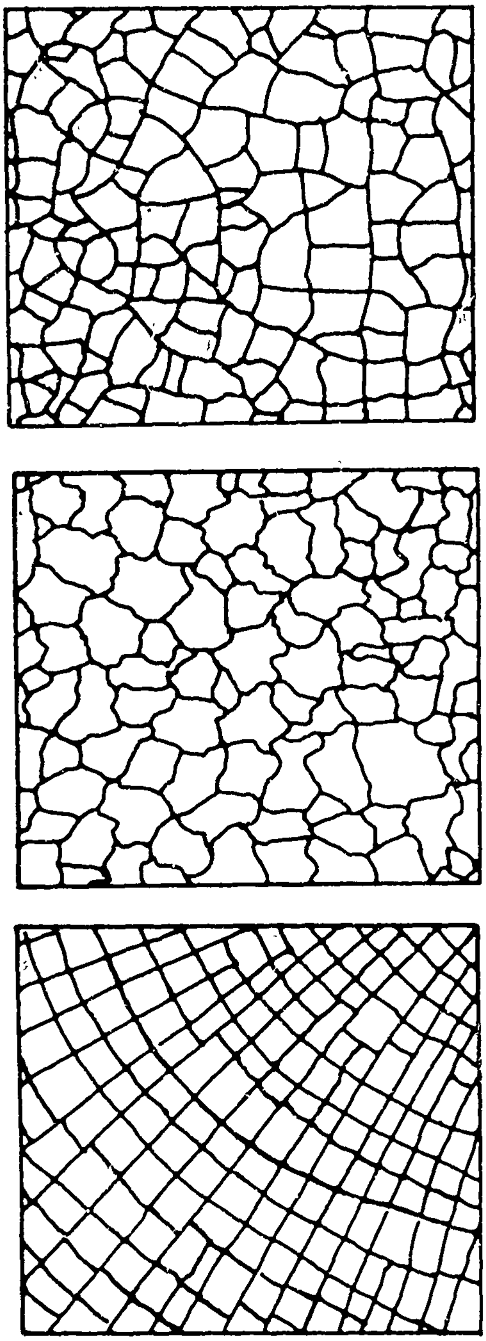
Playa studies fall under the more general study of landforms. Landform analysis deals with the origin, morphology, and crustal features of geographic regions. Such studies have been a basic part of AFCRL's geology research program for well over a decade. Over the years, AFCRL has thoroughly investigated the terrain of arctic ice-free land, snow and ice, but these studies have been largely discontinued. The Laboratory has now evaluated in a general way much of the world's desert terrain. But to date, only a small portion of the landforms of tropic environments has been studied. For obvious reasons, the Laboratory plans to give increased attention to these environments.



Changes in moisture content of dry lake beds produce fissures of the type shown here. Such fissures may preclude the use of a particular dry lake bed as a natural aircraft runway.

REMOTE SENSING: Remote sensing is a means of acquiring ground data through airborne and satellite surveys. This research includes not only the measurements themselves but the development of airborne sensors and of techniques for interpreting the geological significance of their photographic, radiometric and spectroscopic data. The advantages of airborne surveys are clear. They permit access to inaccessible regions otherwise geographically denied, and they often obviate the need for field investigations which are time-consuming and expensive.

Instrumentation and sensors for airborne surveys—some already in use or test, others still under development—are of many types. Taken together, they cover a major segment of the electromagnetic spectrum from VHF through infrared, visible, UV and gamma-ray wavelengths. Among the sensors under development are a non-imaging radar system that can detect soil moisture at various depths, a passive microwave sensor that in field tests conducted to date has shown a capability for measuring moisture levels in soils and snow at various depths, and a pulsed VHF radio propagation system to measure soil and ice thickness and layering characteristics. At the shorter wavelengths, other



Mudcracks in dry lake beds take one or another of three characteristic geometries illustrated here. The most frequently occurring pattern is top pattern in this set.

techniques are used, one of these being polarized light photography.

An instrument that has become basic to AFCRL's airborne surveys is a nine-lens, multispectral camera system for taking nine simultaneous photographs each at a different narrow-band region of the visible and near-infrared spectrum. By studying the tonal contrasts of the resultant photographs, scientists can determine terrain characteristics. In addition to the multispectral camera, other instruments aboard AFCRL's C-130 survey aircraft include a thermal infrared optical-mechanical scanner and several special purpose conventional aerial cameras.

During the reporting period, AFCRL conducted surveys in the arctic, the tropics of Central America, and Middle Eastern desert areas. The most comprehensive survey took place in May and June 1966 and carried the AFCRL scientists over several Mediterranean and Middle Eastern countries, including Italy, Libya, and Jordan. While the C-130 was in the area, the Italian Government asked AFCRL to use its airborne equipment to help locate geothermal areas in Italy that might serve as natural energy sources for electrical power generators. The thermal infrared scanner was used for these surveys. One objective of the Middle East survey was the observation of large, dry flat areas that are comparable to playas in the U. S.

At the request of the U. S. Geological Survey and the Icelandic Government, the dynamic geothermal region of the Surtsey volcano was studied during the summer of 1966. The AFCRL scanner was flown to generate imagery of thermal anomalies and patterns for correlation with ground temperature measurements. Such airborne techniques can yield valuable information on geothermal studies in worldwide areas such as

By photographing the same scene in different spectral regions of the visible and infrared, it is possible to define terrain properties with a high degree of precision.

Hawaii, the Aleutian Islands and the Philippines.

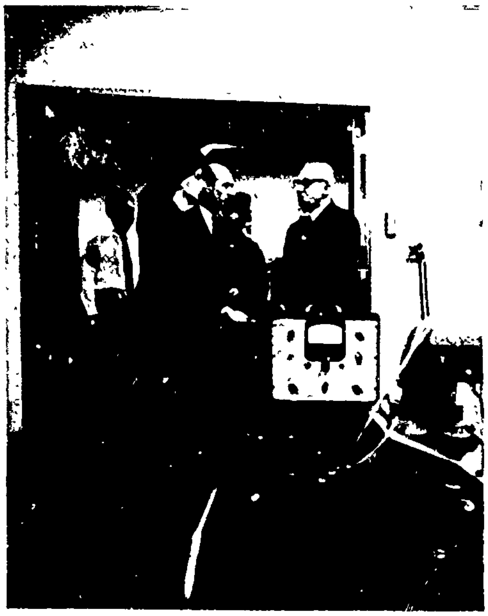
The airborne sensing program is being extended to satellite altitudes, with the present emphasis devoted to photographic interpretation. Under this program, general terrain patterns of geologic significance are correlated with available photography from high altitude aircraft, rocket and satellite flights. Gemini photography in particular shows much promise for delineation of landform patterns.

The extension of the Laboratory's work into terrain photointerpretation research was marked by the establishment of a new photometric capability devoted to furthering the interpretation of geologic photography. Interpretation of sensor data, photographic or other, is often a matter of some theoretical complexity, involving radiant energy distribution, spectral reflectance of materials, and atmospheric transmission properties affecting spectral imagery interpretation. Laboratory and field experiments are providing such needed data under controlled conditions.

GRAVITY

Gravity values at all locations on the earth's surface and in the earth's gravitational field are not known with precision. The objectives of AFCRL's gravity research program are the development of theories and mathematical methods for the description of the earth's gravitational field, the determination of gravity dependent earth constants and the development of theories and methods for the prediction and interpolation of gravity values at locations where no measurements have been made. An intrinsic part of this research is the development of gravity instrumentation of greater sensitivity and efficiency. To test and calibrate new instruments, AFCRL scientists transport them to widely spaced geographical areas. To evaluate instruments for airborne surveys, the Laboratory uses an instrument-carrying KC-135 aircraft.

The AFCRL gravity program is closely tied to a large concerted international program which has been in progress since 1962. In April 1967, AFCRL was host to a meeting of the Working Group for World Standard and First Order World Gravity Network. Among the general problems engaging the attention of AFCRL and other national and international investigators in this rather specialized field are the establishment of a worldwide calibration standard, measurement of absolute gravity in terms of fundamental units, gravity measurements at the surface and above the earth, gravity prediction between surface



Soviet scientist Professor Yuriy D. Boulanger, Director of the Institute of the Physics of the Earth's Interior, listens as AFCRL scientists discuss a gravity measurement program. During his visit at AFCRL, Professor Boulanger lectured on gravimetry in the USSR.

values, upward continuation of gravity values to high altitudes from the surface field, and the reduction of aerial gravity measurements to required mean surface values.

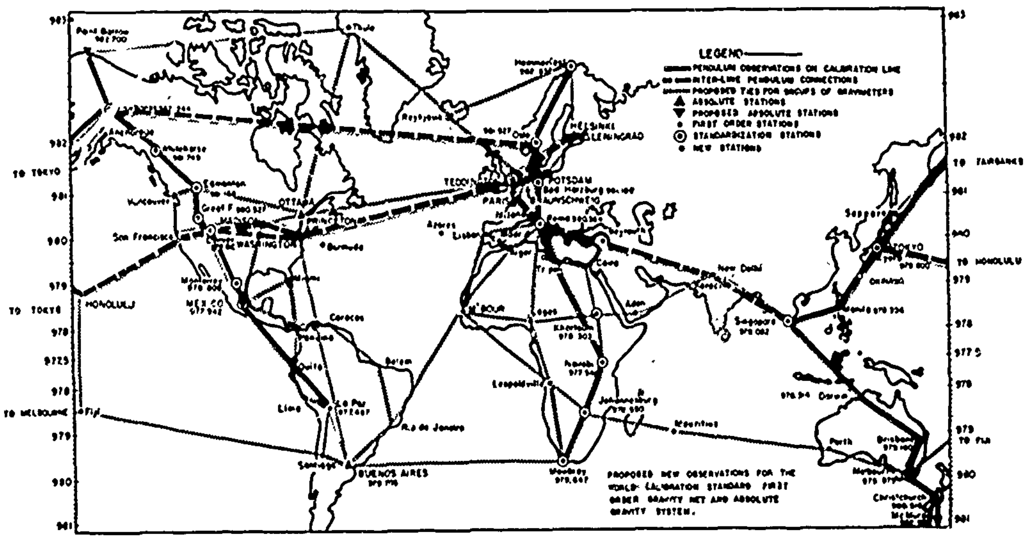
Studies of the earth's gravity and gravitational fields, from the standpoint of Air Force operations, relate to inertial navigation and the guidance of long range missiles.

THE EXTERNAL GRAVITY FIELD: The external gravitational field of the earth refers to the gravitational attraction of the earth at various distances from its surface. This attraction varies with the mass distribution of the earth. If the earth were a smooth sphere of homogeneous composition, gravity calculations would be relatively easy. Given a few data points, it would be simple to calculate gravity fields with great precision. Because the mass distribution is irregular, the gravitational field varies in a manner not easily predictable.

AFCRL hopes to develop techniques for deriving information on gravity values all over the earth and at all altitudes based on limited measurements. Several methods are being investigated for doing this. The problems concerning the "upward" continuation of gravity values to high altitudes from the anomalous field observed at the surface have been solved and various methods, including computer programs for handling a large number of points, have been tested and results published. Theoretical solutions for the "downward" continuation problem are also available. This means that measurements made with AFCRL's airborne gravimeters can lead to the computation of surface mean values from gravity profiles observed at various altitudes. Correlation studies and statistical methods have been made and published for estimation of gravity anomalies in unobserved or inaccessible areas.

The harmonic coefficients derived from various satellite solutions have been compared and evaluated in terms of mean anomalies and geoid undulations. As a continuation of this effort a new approach for the combination of satellite and terrestrial gravity data is being investigated and applied to the currently existing material.

WORLDWIDE GRAVITY SYSTEM: The Worldwide Gravity System had its beginning in September 1962 at a meeting of the International Gravity Commission in Paris. AFCRL was a major participant at the meeting, and had taken the initiative in seeking a worldwide gravity standardization program. Until the meeting, the critical problem was



The basic framework of the world gravity net are three north-south calibration lines stretching from Point Barrow, Alaska, to Lima, Peru; from Hammerfest, Norway, to Mowbray, South Africa, and from Fairbanks, Alaska, to Christchurch, New Zealand.

the lack of a uniform standard for calibrating gravity measurement instrumentation, and the lack of a worldwide network of base stations needed to integrate various local gravity measurements into a single uniform net.

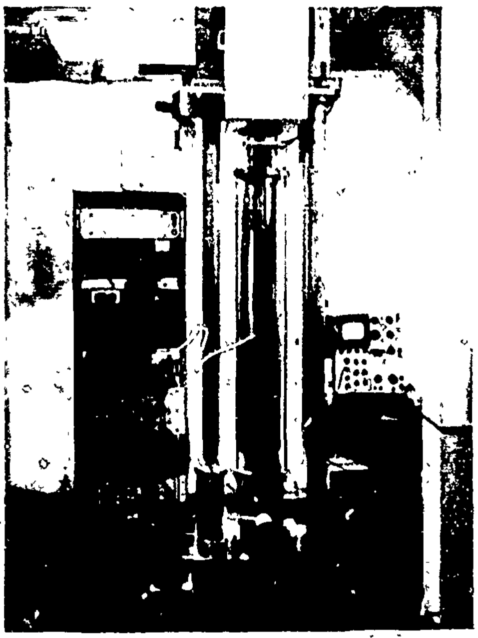
Three interrelated parts make up the absolute world gravity system: an accurate world calibration standard, a first-order world gravity net, and an international absolute reference system.

The starting points of the worldwide gravity system are three north-south calibration lines, along each of which are eight or nine primary standardization stations. These are the American calibration line, extending from Point Barrow, Alaska, to the southern tip of Argentina; the Euro-African calibration line, extending from Norway to South Africa, and the West Pacific calibration line, extending from Fairbanks, Alaska, to New Zealand.

Many international agencies are cooperating in the overall program, which is currently on schedule. Observations along the three major standardization lines (Euro-African, American and West Pacific) were completed at the end of 1965. Horizontal connections between the standardization lines were made during 1966. The 1967 field program will consist of pendulum and gravimeter measurements for verifications and checks where the disagreement of existing data is larger than reasonable.

The absolute gravity experiments are progressing satisfactorily. During 1967, a preliminary correction to the present Potsdam reference values will be made. This is expected to be achieved by measurements at several key stations by a new type of gravity measuring device, a free-fall/laser instrument discussed in the next section. Measurements at the same sites by a different portable apparatus are expected during 1968.

GRAVITY INSTRUMENTATION: Only in recent years have instruments been developed of sufficiently high precision to permit the establishment of worldwide gravity standards. One of AFCRL's



This laser-interferometer gravity device measures the effects of gravity on an optical cube falling through the drop chamber shown.

foremost contributions to gravity research has been in airborne instrumentation. AFCRL airborne equipments have steadily improved since AFCRL performed the first successful airborne tests in 1958.

During 1965 and 1966, AFCRL intensified efforts to improve airborne gravity measuring systems. A total of 400 hours were flown over selected test areas with modified LaCoste and Romberg and Graf-Askania airborne gravimeters. During 1966, a Worden digital quartz gravity sensor with related electronics was also flight tested. In addition, a TITAN-II Type 25 Pendulous Integrating Gyro Accelerometer (PIGA) was modified for aerial gravity use and installed in the AFCRL test aircraft late in 1966. Flight tests of this new instrument were made in December 1966 and January 1967. The preliminary reduction of the experimental test data indicates that an accuracy of plus or minus 7–8 mgal was achieved for the mean anomalies within longitude-latitude squares of five degrees. (Gravity is measured in mgals. The best accuracy obtainable with ground equipment at a particular location is plus or minus .02 mgal.)

For land measurements, AFCRL uses three different types of gravity instruments: gravity meters, pendulums, and free-fall devices. Earlier work at AFCRL was concentrated on gravimeters and pendulums. More recently AFCRL has turned its attention to a laser-based free-fall device. In such a free-fall device, an interferometer mirror is the dropped object, with a gas laser serving as a visible light source.

These different types of gravity instrumentation possess relative advantages and disadvantages. Gravity meters are more sensitive than pendulums, but pendulums at present permit the observer to establish relative values between two sites having large gravity differences.

With gravity meters (the basic mechanism of which is a spring and weight), the relative differences in gravitational acceleration at two or more sites can be measured very accurately, provided the instruments are well calibrated for measurements within a restricted range of values. But if the gravity meter is used at another site where values exceed this restricted range, then the instrument is subject to unpredictable systematic error. Pendulums can be used for both absolute and relative measurements of gravity. Pendulum devices are based on the principle that the period of a pendulum of a given length will vary with the acceleration of gravity at a given location. If both the length and period of the pendulum are determined in an experiment, the result will be absolute. If only the period is observed at two or

more sites and the length assumed to remain constant, the results will be relative gravity differences between the observation stations.

More recently, however, improvements in the free-fall devices have brought them to the point where their accuracy exceeds that of absolute pendulums. Such devices will be increasingly used in future measurements—not as a replacement for the absolute pendulum, however, but in concert with it. These two distinct type instruments yield independent gravity values with different systematic error sources thereby permitting increased confidence in final mean values.

Absolute gravity measurements with a recently developed reversible pendulum apparatus and the new laser-interferometer free-fall apparatus are planned by AFCRL in 1967 at the fundamental gravity station in Washington, D. C. A one-year program of measurements at other fundamental world stations will be carried out in 1967 and 1968.

In addition to these instruments, another absolute gravity device is under development by AFCRL and fabrication of the first model began in the spring of 1967. Absolute gravity will be determined from measurements of the trajectories of charged particles in a condition of free rise and fall. Fabrication was preceded by extensive testing and modification of experimental laboratory equipment.

The component of interest here is the white vacuum chamber on the right which contains a reversible pendulum apparatus. The vacuum pump in the center foreground removes the air from the chamber to permit the free swing of the pendulum without air resistance.

GEODESY

Along with the space age came new requirements for information on the size and shape of the earth. Guidance system accuracy of aerospace ballistic and satellite vehicles is a function of how well distances, directions and positions between launch sites and destinations are known.

Satellites have become basic tools for measuring distances and directions between points on the earth's surface. More recently, in measuring intermediate distances, the Laboratory has experimented with balloon techniques. In both the satellite and balloon situations, the measurement principle is the same. It consists of photographing an object against a background of stars from two or more widely spaced cameras, and calculating distances and directions between cameras by triangulation.

AFCRL, NASA, other USAF agencies, Army, Navy, civilian agencies and observatories make up the widely diversified cooperating agencies that are participating in a worldwide effort to establish a network of geodetic stations, whose positions will be determined from satellite observations.

For satellite triangulation, both active and passive satellites are used. An

active satellite carries its own illumination; a passive geodetic satellite either carries reflectors for redirecting ground-based light, or is any satellite that reflects solar light which is visible from the ground. On 6 November 1965, the GEOS-A active geodetic satellite was placed in orbit, joining the first active satellite, ANNA-1B, which was launched three years before. ANNA-1B's lights are still (June 1967) flashing. The optical beacons aboard the GEOS-A satellite malfunctioned on 1 December 1966. Closely related to geodesy is selenodesy—another Laboratory program—which is concerned with the size and shape of the moon, with its libration and with distances between points on the lunar surface.

GEODESY WITH ACTIVE SATELLITES: The National Geodetic Satellite Program involves many agencies, with close interagency planning. AFCRL, together with other agencies, operates camera sites and interprets results. At the latest count, USAF observations of ANNA-1B had produced 1104 plates with flash images. The Aeronautical Chart and Information Center reduces the camera plate data and computes geodetic positions and azimuths. Military Airlift Command's 1381st Geodetic Survey Squadron performs the camera observations. The ANNA data are used to compute geodetic positions for observing sites well over 1000 km apart. Station positions determined from observations of ANNA have internal consistencies averaging as high as one part in 400,000. ANNA is also monitored to learn more of orbital dynamics and the forces enacting on satellites, and has yielded valuable data on the long range behavior of high intensity optical beacons in space.

Visitors to AFCRL view a model of Anna 1-B on display in the Laboratory's main lobby. This satellite, the first ever instrumented for geodetic purposes, was part of a research program that demonstrated the feasibility of using photographic satellite surveying techniques to derive significant geodetic data.

The various radio and doppler ranging and angle measuring devices aboard GEOS-A have recently failed, as have the optical beacons. Until the malfunction, 773 photographs were collected. Station positions computed from doppler, transponder, and optical observations of GEOS-A are in agreement with NAD 1927 datum surveyed positions of the observing sites to within five meters in latitude, longitude and elevation.

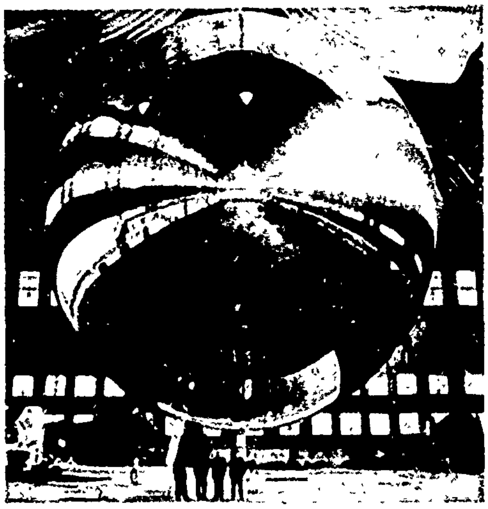
GEODESY AND PASSIVE SATELLITES: Passive satellites used in geodesy studies are satellites that are illuminated by external light sources such as sunlight or by lasers from the ground. Simplicity, economy and lifetimes measured in decades or centuries are the basic reasons for this interest. The most important passive geodetic satellite launched during the period was PAGEOS, a reflective balloon satellite of the ECHO type. It was placed in orbit on 24 June 1966. AFCRL is exploring three methods for optimum use of passive satellites.

First, several types of large aperture, high-speed shutters have been developed for USAF's long focal length cameras. These shutters permit precisely timed photographic chopping of traces of sunlit illuminated satellites. Observations by several cameras within the same time span can be used in a manner similar to procedures utilizing ANNA flashes to compute relative positions of the observing sites. This technique is now being tested with cameras stationed in Spain, Bermuda, and the United States. The goal is that of obtaining precise transoceanic geodetic positions.

A second method of using passive satellites is to deploy a network of several geodetic stellar cameras which simultaneously photograph the continuous trace of sunlit satellites against the stellar background. This technique does not require the precisely timed traces, but places the burden of developing geodetic positions on a computer. AFCRL recently completed a photographic survey of passive satellites which would yield suitable continuous trace images for development of geodetic positions. This survey determined that at least 12 different objects presently in orbit can be used as image sources for continuous trace geodesy.

The third AFCRL passive satellite technique is one in which specially designed external reflectors are placed on the satellite to return high intensity light pulses to their ground source where they can be photographed for angular information and evaluated photoelectrically for ranging information. Three satellites of the Explorer series now carry prismatic reflectors which can reflect a light signal back to the source.

AFCRL began work on this third technique in 1963 with initial experiments consisting of laser firings along a 50 km horizontal path to evaluate heterogeneous atmospheric conditions and the photographic properties of laser beam images. Later tests in 1965 successfully demonstrated that a laser pulse could be reflected from a satellite and photographed by geodetic stellar cameras.



PAGEOS, a reflective balloon satellite of the ECHO type, was placed in orbit on June 24, 1966. It was the most important passive geodetic satellite launched during the two-year reporting period.

In continuation of this program, AFCRL is exploring a technique for controlling and programming the laser discharge to precisely timed output pulses. This work has led to a new laser that employs a Kerr cell Q-switch to control its firing. Moreover, it has been found possible to program the laser with several giant pulses at precisely timed intervals during a single pumping period. The theoretical study of such a laser has been completed and exploratory measurements with a breadboard unit have been made at terrestrial, line-of-sight distances. To date, these early measurements are limited by data reading resolutions and lack of precise timing of the pulse programming circuitry. Experimentation in this area of laser ranging is continuing.

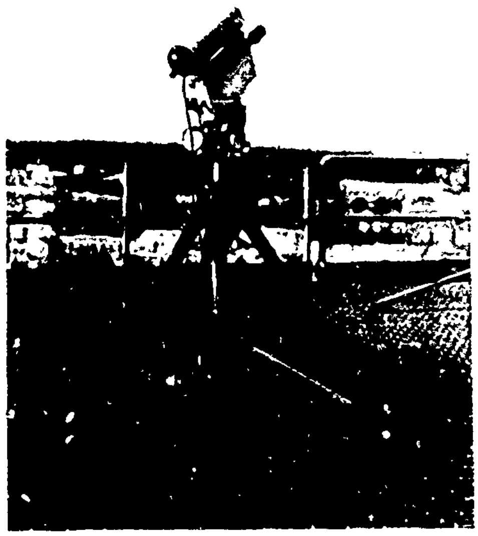
BALLOON TECHNIQUES FOR GEODESY: AFCRL and contractor personnel have devised a lightweight, self-contained flashing light suitable for use as a balloon payload for photographic triangulation. The principle is similar to satellite triangulation but the recording cameras are only 150–250 km apart. A field test of this technique in the Holloman AFB, New Mexico, area shows it has potential in permitting relatively inexpensive densification surveys between the national primary control networks and the worldwide satellite observing sites network. Flash images were recorded photographically during the test at ranges up to 200 km.

GEODETIC MATHEMATICS AND COMPUTATION: All of the new techniques of geodetic measurement using satellite information require mathematical methods for data reduction and position computation. For this, the geodesist turns to electronic computers to solve the complicated mathematics and to handle the mass of data generated in satellite geodesy observations.

Precise timing of observations and precise knowledge of time differences between the sites observing a given event are problems receiving some attention. A computer program to produce geodetic positions from observations of the same portion of a sunlit satellite's orbit by several cameras is completed and is awaiting test data.

Another geodetic computer research program involves geometric error analysis to determine the most efficient observing station deployment and the best type of measurements to yield the most accurate geodetic positions from intervisible observing techniques.

The following additional software programs were developed during the period: 1) a set of computer programs for performing analytical calibrations of metric camera lens systems, 2) a computer program for geodetic positioning by the Method of Continuous Traces, 3) a computer program for determining station position from simultaneous and non-simultaneous observations of right ascension and declination by ground observers, 4) a computer program that will mathematically integrate range data from either simultaneous or non-simultaneous observations, and 5) a computer program which modified the DOC-II program to allow the parameter estimates to reflect *a priori* information on their variances.



This simple laser apparatus located on a rooftop at AFCRL was the basic instrument used by AFCRL in laser geodesy studies in which a light is reflected from a passive satellite.

SELENODESY: Selenodesy is the study of the size, shape and mass distribution of the moon, or the extension of geodesy to the moon. The basic data for such studies have in the past been derived

from direct heliometer observation and from photographs of the moon. Although selenodetic photogrammetry is a continuing aspect of the work of the Laboratory, major emphasis during the reporting period was placed on the development of two closely related lunar laser experiments.

One of the experiments—the ranging experiment—is designed to detect small variations in the moon's motion. The time that it takes a pulse from a ten joule ruby laser (Q-switched mode) to be returned from the cube corner reflector on the moon will be measured. The pulse will return to the same telescope through which it was transmitted.

The second experiment is photographic. In this experiment a 40 joule ruby laser pulse (normal mode) will be transmitted through the telescope, but a second 1.5 meter aperture telescope will be used to detect the returned signal as a photographic image.

Both experiments involve placing a single cube corner reflector on the lunar surface. Both also make use of a 1.5 meter aperture telescope through which a ruby laser pulse will be directed to the lunar target, but separate receiving optics will be used.

The moon's rotation constants which could be redefined as a result of these experiments are the inclination of the moon's equator to the ecliptic which is known to about 1 part in 100, and its mechanical ellipticity, involving lunar moment of inertia ratios which are known to about 1 part in 10. With the sensitive lunar laser ranging technique under development, which will have a range resolution of only a few meters, lunar moment of inertia ratios can be expected to be improved to about 1 part in 100.

There are many uses for precise range information to a specific point on the lunar surface. For example, sampled laser observations throughout the lunar libration cycle will allow independent checks on the moon's mechanical figure and provide observations useful in calculating an improved physical ephemeris of the moon. An accurate check on lunar theory (parallax) could be performed. Such observations may also provide an independent check on the earth's equatorial radius.

Optical packages suitable for soft landing on the moon are being fabricated and tested. Such an optical package contains one or more cube corners, a sun shield, and holding devices. Its passivity, relatively small mass, and simple design are desirable characteristics.

If several optical packages are located on the moon, distances between them could be measured on photographs. An understanding of these data could provide a better understanding of lunar positional uncertainties which exist in currently available selenodetic control networks.

In a series of planned experiments in which a reflector is placed on the surface of the moon to reflect light from an earth-based laser, AFCRL hopes to redefine certain of the moon's rotation constants.

LUNAR PROFILE STUDY: Photographs collected by three AFCRL-sponsored annular eclipse expeditions in 1962, 1963, and 1965 have been studied. An annular eclipse is one in which the lunar disk does not completely obscure the sun but is silhouetted against it. Analysis of annular eclipse photographs uses the solar profile as the reference circle to determine the general shape of the moon. Photographic exposures were made with a 12-inch aperture f/57 mirror which produced solar images approximately 6.5 inches in diameter. Photographic analyses indicate a possible lunar equatorial bulge, but further investigation must be completed to determine if the bulge is real.

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X Optical Physics Laboratory

The Optical Physics Laboratory is concerned, basically, with atmospheric effects on optical radiation—electromagnetic radiation in the ultraviolet, visible and infrared regions of the spectrum. The atmospheric transmission of infrared radiation is of special concern. Atmospheric influences are many: refraction, scintillation, absorption, scattering, and so on. These effects often set limits on the performance of Air Force reconnaissance, surveillance, communications and detection systems. Intrinsically related to atmospheric transmission studies are Laboratory programs to develop better infrared and other optical devices. A sizable segment of the total Laboratory program is observational, entailing instrumentation of rockets, missiles, satellites, balloons and aircraft.

The wavelengths of interest to the Laboratory range from 1000 angstroms in the ultraviolet portion of the electromagnetic spectrum, to 1 millimeter (10 million angstroms), where the far infrared blends into the microwave radio frequency spectrum. Only a small fraction of this broad spectrum of wavelengths is in the visible light region, but this segment is of special interest. Devices used to measure radiation throughout the optical region include spectrometers, interferometers, photometers and radiometers, each suitably designed to measure particular segments of the spectrum.

The Laboratory's sizable observational programs are supported by theoretical and laboratory experimental research. As part of its atmospheric chemistry research, the Laboratory during the reporting period initiated a new effort in

This diagram illustrates atmospheric effects on optical signals. Incident light (from the sun or moon) illuminating an object is designated Io. The amount of light reflected from an object is designated R. As altitudes increase, the amount of IoR available for detection decreases because of scattering. In addition, path radiance, or the light which illuminates the atmosphere itself, also combines with IoR to increasingly deteriorate the optical signal. The atmosphere itself acts to deteriorate optical signals by introducing a transmission function T. To further complicate matters, all of these functions are wavelength and weather dependent.

molecular beams. Because molecular beam generators capable of accelerating molecules in the relatively low energy range of one to ten electron volts were nowhere available, the Laboratory undertook the task of designing and building such generators. The one to ten electron volt energy range is of unique importance because most chemical reactions, whether in gas or in liquid, are initiated by molecular collisions in these ranges. The Laboratory is studying several different equipments for the generation of low energy molecular beams.

Laser research is also conducted by the Optical Physics Laboratory. (An additional laser effort concerned with semiconductor lasers is carried out by the Solid State Sciences Laboratory, Chapter VII). Two solid state laser problems are under investigation. One main area of investigation is the correspondence between laser theory and kinetic theory of gases and plasmas. The second main area of study is solid state laser devices. The effort during this reporting period was concentrated on the enhancement of laser brightness by compensating for optical distortions which develop when the laser rod is energized.

TRANSMISSION AND BACKGROUND RADIANCE

Much of the work of the Laboratory is observational. The Laboratory places its instruments on satellites, rockets, missiles, balloons, and aircraft. Observations are also made from the ground. Measurements for the most part involve the transmissions of UV, visible and infrared energy through the atmosphere. The study of background radiance is also a strong component of the overall program.

Five satellites and one Nike Cajun rocket launched during the reporting period carried Optical Physics Laboratory equipments for making transmission and radiance measurements. The satellites were the Gemini 5 and 7, the OV1-5, the OV1-86, and an Agena. (The instrumentation of three additional rockets and five missiles is discussed later under "Infrared Research.")

Three aircraft were used by the Laboratory in its radiance measurement program. One of these was the X-15 Air Force-NASA aircraft which was used by the Laboratory for making UV reflectance measurements of the atmosphere. The other two aircraft are a C-130 and a

KC-135, both carrying a range of optical instruments for airborne observations. The KC-135 during the period was extensively refitted and reinstrumented.

The purpose of these observations is to pr·ide the Air Force with the capability for predicting the performance of various optical systems under a variety of operational circumstances at different altitudes and geographic locations, and during both daytime and nighttime operations. The purpose is also to produce data for the development of better sensors and detectors for such Air Force operations as reconnaissance, target-background identification, detection and tracking of airborne and space targets.

KC-135 OBSERVATIONAL LABORATORY: A KC-135 aircraft completely reinstrumented for making airborne observations of optical energy transmissions in the atmosphere was delivered to AFCRL in May 1967. The aircraft is a unique observation platform and will give Laboratory scientists the mobility for making measurements all over the world. Studies planned for the 1967–1968 period are investigations of the infrared aurora and airglow as a function of latitude and season, the study of atmospheric water vapor in the altitude regions of 7 to 12 kilometers as a function of season and geographic location, and the evaluation of infrared techniques for use in Southeast Asia to detect targets from an airborne platform.

Nine newly developed instruments were installed in the aircraft. The new equipment includes: an electronic scan spectrometer, an infrared sky mapper, five Michelson interferometers, and two infrared radiometers. Conventional supporting instruments installed include a visible spectrometer, a visible sky mapper, a greenline photometer, a filter photometer, and all-sky and documentary cameras.

This KC-135 flying laboratory was reinstrumented in 1967 at a cost of a third of a million dollars for atmospheric optics research. Among the instruments aboard are the monitors shown below associated with three interferometer spectrometers covering the 1 to 14 micron range.

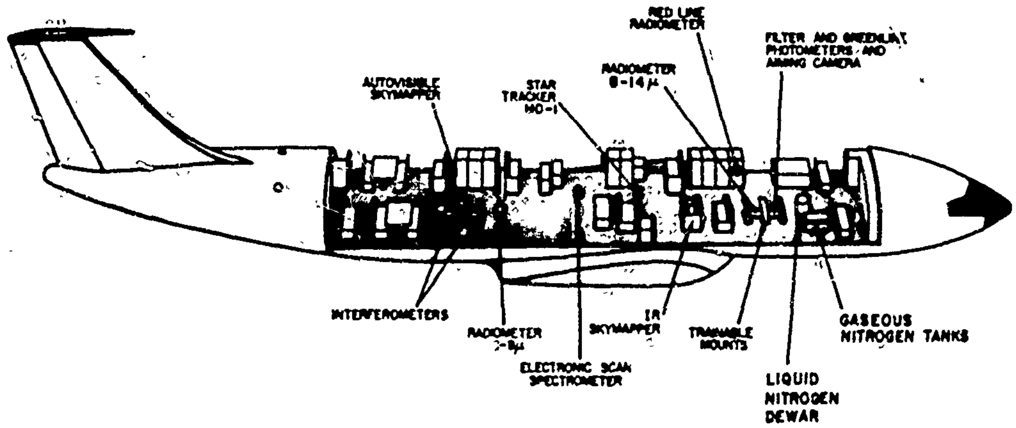
Other equipments on the aircraft greatly enhance its overall capability. A servo-controlled slave complex links together seven separate instruments for simultaneous tracking of a given observational area. The KC-135 carries a data

recording system consisting of five 14-channel analog magnetic tape recorders and a video magnetic tape recorder with special timing and indexing features. An MD-1 Astro Tracking system gives aircraft position information in areas lacking adequate navigational aids.

BACKGROUND RADIANCE: The basic problem underlying the Laboratory's observational research is that of seeing a target within the clutter of light scattered by the atmosphere. It would be well to comment in an elementary way on the general physics of the situation. Things are seen or detected by remote sensors because they reflect or emit radiant energy. A photometer, looking down at the ground, receives light reflected from the ground and transmitted through the atmosphere. It also sees light that has been scattered into the direction of the detector by the atmosphere itself, the so-called path radiance. Different objects radiate at different characteristic regions of the optical spectrum. Thus, a particular target is seen most clearly by detectors designed to operate in a narrow spectral region keyed to the target of interest.

To identify targets by means of their characteristic radiations, instruments with good spectral and spatial resolution are necessary. Such resolution at specified spectral bands is needed to limit the cluttering background of scattered light, thus achieving better target-to-background contrast. To obtain clearer target signatures and to limit atmospheric effects on target definition, the sensor-target-sun geometry can have a large role. Observations must be interpreted in terms of such illumination conditions.

One important advance made by the Laboratory during the period was not only improved instruments themselves, but also better calibration techniques.



This drawing shows the placement of equipments in AFCRL's KC-135 aircraft, one of the best instrumented facilities in the world for conducting research in atmospheric optics.

AFCRL has established one of the finest laboratory calibration facilities in the country. Many of the calibration instruments were designed in-house by AFCRL personnel; others were developed for AFCRL under contract.

A facility widely used during the reporting period for background radiance measurements was the Laboratory's C-130 aircraft. This aircraft, while it does not have the diversity of instruments of the recently reinstrumented KC-135 aircraft, is nevertheless one of the best equipped airborne platforms in the world within its specialty of atmospheric optical studies. During the reporting period scores of flights were made. These flights were supplemented by observations made from satellites, rockets, and balloons.

Special ultraviolet reflectance measurements in the 2400–2800 angstrom region were made with an AFCRL instrument aboard the NASA-Air Force X-15. Solar ultraviolet radiation is largely absorbed by the atmosphere before it reaches the earth. Because such a small amount does in fact reach the earth, one would not expect that the residual reflected UV could again traverse at atmospheric layer in quantities sufficient for detection at high altitudes. The experiment was designed to find out if ultraviolet radiation reflected from the earth could be detected by airborne sensors at extreme altitudes. Results were inconclusive.

BALLOON-BORNE AND ROCKET INSTRUMENTATION: During the reporting period, the Laboratory launched 16 balloons to altitudes as high as 40 kilometers to measure background radiation and the characteristic radiations of terrain background.

Special emphasis was placed on measurements of earthlight. The basic payload for these flights consisted of 27 dif-

Little is known about zenith atmospheric scattering between altitudes of about 40 and 140 km. To measure scattering along this vertical path, rockets were used. The angle of the sun is critical to scattering calculations.

ferent photometers mounted so that they pointed downward. The spectral range covered by the whole photometer array was from 3900 to 9100 angstroms. Each photometer had a filter centered on a different wavelength at 200 angstrom intervals. Bandpass of each was 75 angstroms. Also included in the array were cameras for taking color photographs of the terrain below. In this way, the features of the reflecting surface were identified. All data were recorded by an onboard, seven-channel magnetic tape recording system.

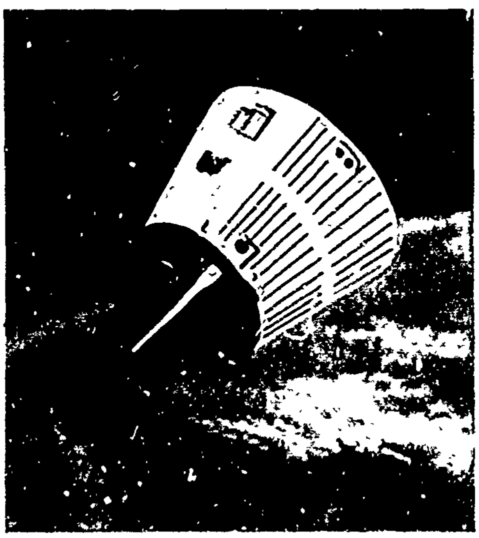
Balloon measurement of skylight, particularly in the spectral region between 2000 and 4000 angstroms, necessitated the development of special instrumentation because of the extreme variation in the intensity of scattered light in this spectral region. A spectrometer was coupled to a solar biaxial pointer, and was mounted in such a way as to scan in a vertical plane from the horizon up to the point where the balloon obscures the sky above it. The solar biaxial pointer keeps the sun in this vertical

scanning plane at all times, so that the intensity of skylight as a function of the angle between the sun and a particular portion of the sky can be determined.

This spectrometer not only measures the intensity of skylight but also the degree of polarization of the radiation. Polarization is an important parameter in target discrimination.

Balloons can carry instruments to about 40 kilometers to make measurements of the overhead skylight. Little is known about zenith scattering between that altitude and the altitude of orbiting satellites. This led the Laboratory to launch from Eglin AFB, Florida, on October 30, 1966, a rather ingeniously designed rocket for measuring the intensity and polarization of zenith sky spectral radiance.

The experiment consisted of seven photometers symmetrically arranged with each optical axis parallel to the longitudinal axis of the rocket carrier.



Astronauts aboard the Gemini 5 and 7 made some 30 different AFCRL-designed infrared and ultraviolet measurements of the oceans, the earth, the sky, clouds, stars and other satellites.

All photometers had the same construction except for different narrow-band interference filters designed to transmit radiation at 3750, 4150, 4350, 4550, 4750 and 5550 angstroms. Because sky brightness varies by at least three orders of magnitude over the 40 kilometer vertical measuring path of the rocket, a photometer that would be sensitive to levels of sky brightness at one part of the flight would be saturated at the others. This was overcome in the successful rocket flight by altering the sensitivity (by changing voltages) of the instruments in a prescribed timing sequence during flight.

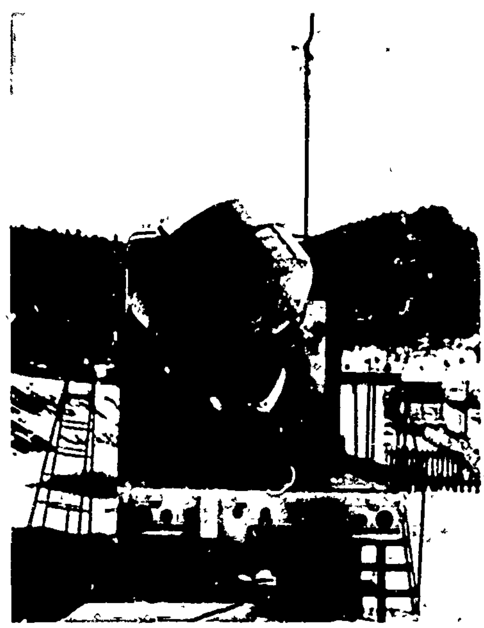
SATELLITE MEASUREMENTS: During and immediately subsequent to the reporting period, Optical Physics Laboratory scientists instrumented five satellites. AFCRL-designed instruments and experiments were carried on the Gemini 5 and 7 launched in the latter half of 1965, on the OV1-5 launched on March 30, 1966, the OV1-86 launched on July 27, 1967, and an Agena rocket launched in early August 1967. The experiments aboard all these vehicles were closely related.

The Gemini 5 and 7 astronauts were scheduled to make some 30 different AFCRL-designed infrared and ultraviolet measurements of the oceans, the earth, the sky, clouds, the moon, stars, other satellites, and ground targets. Three instruments were used—a two-channel infrared and UV radiometer (each with ten filters for observing at different wavelengths), a liquid-neon-cooled infrared interferometer, and an uncooled infrared interferometer. The spectral region covered by these instruments extended from 0.22 to 15 microns. Approximately three hours of data were gathered on each flight. Most of the measurements were made in the spectral

region of 0.22 to 2.7 microns, including land, water, and cloud reflections, and the Gemini 6 rendezvous vehicle. A Polaris missile vapor trail was measured between 0.22 and 2.7 microns and a remote orbiting vehicle between 8 and 13 microns.

The OV1-5 satellite launched in March 1966 was equipped with two interferometer-spectrometers and three radiometers containing a total of nine detectors for measurements from 0.22 to 30 microns. The OV1-86 and Agena, launched in July and August respectively, each carried an interferometer and a boresighted radiometer for selected infrared spectral measurements between 2.2 and 4.3 microns. Because spectral and radiometric data from the two Gemini vehicles and the OV1-5 indicated the need for increased sensitivity in selected regions of the infrared, both the OV1-86 and the Agena spectrometers were provided with cooled detectors. The successful integration of a thermoelectrically cooled, evacuated detector with a satellite-borne interferometer constitutes a state of the art improvement in satellite spectrometer design.

SEARCHLIGHT SCATTERING OF AEROSOLS: Aerosols scatter light according to the Mie theory which applies to particles whose diameters are the same order of magnitude as the wavelength of incident light. Mie scattering does not depend on wavelength as much as does molecular, or Rayleigh, scattering in which the particles (molecules) are several orders of magnitude smaller than the wavelengths of the light they scatter. Since aerosols scatter light less selectively, they produce a characteristic white haze when present in high concentrations. Aerosol scattering is much more difficult to predict than molecular scattering because of its greater variability in time, location and altitude. During the period July 1965 through June 1967, the Laboratory continued its investigation of aerosol scattering in the atmosphere using two techniques: searchlight probing and observing of the solar aureole.



This narrow beam searchlight at White Sands, N. M., was used by AFCRL to measure aerosol content of the atmosphere. Backscattered light from the searchlight beam was observed and recorded 30 km away at AFCRL's Sacramento Peak Observatory.

Solar aureole observations are used for study of forward scattering of aerosols. The solar aureole is the bright white region around the sun's disk caused by aerosol scattering on hazy days. Measurements of the solar aureole are made by blocking out the sun's disk and measuring the intensity of light in its surrounding halo as a function of the angle between the aureole and the sun.

For the aerosol backscattering study, a narrow beam searchlight was set up

at White Sands, New Mexico. The scanning and recording device was located at AFCRL's Sacramento Peak Observatory, 30 kilometers away. The searchlight beam was pointed upward at a constant angle, and the light collector scanned up and down along the beam, recording the intensity of the light scattered from it at each point. The data were reduced and plotted. The theoretical molecular scattering was then calculated and plotted on the same graph as the total observed backscattering. The difference between the total observed scattering and the theoretical molecular scattering represented the scattering due only to aerosols.

This study was successful in identifying several layers of high aerosol concentration in the atmosphere below 35 kilometers. One layer occurred at ten kilometers, at about the altitude of the local tropopause, where temperature stops decreasing with altitude. (Atmospheric parameters relevant to the study, such as wind, density, and temperature measurements, were recorded during the searchlight experiments by radiosonde balloons.) The tropopause aerosol maximum was unexpected, and further studies to investigate this anomaly are planned. A second, and larger aerosol concentration was formed at about 19 kilometers where the aerosol layer tends to reach a maximum. This result was in good accord with those of other experimenters. Above 19 kilometers, aerosol scattering rapidly decreases, and by 25 kilometers, almost all scattering is molecular scattering.

Aerosol scattering is an important noise background source in the atmosphere's lower region. The Laboratory has been monitoring these aerosol layers by the searchlight method on a regular basis to accumulate historical data on their daily and seasonal variations. (Ultimately, these data may be of use to others concerned with world-wide increases in atmospheric pollution.) A new treatment of the data obtained from this study promises to provide information not only about the optical properties of the atmosphere, but also about the physical properties of the aerosols themselves. The use of lasers instead of searchlights for this purpose is being investigated.

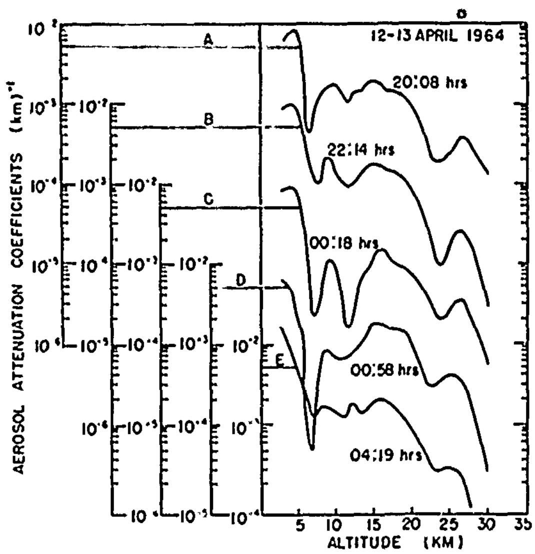
ATMOSPHERIC ATTENUATION MODEL: Observations of the types described in this section become more meaningful when there is a standard against which they can be compared. This has led the Laboratory to formulate a "clear standard atmosphere" which consists of tables of average absorption and scattering values. These tables, formulated on the basis of many observations and their theoretical interpretation, cover the spectrum from the ultraviolet to the near infrared region and altitudes from sea level to several hundred kilometers. This work comprises, in effect, an atmospheric attenuation model where scattering is the primary cause of the attenuation.

Little, if any, visible light is lost in scattering. It is dispersed in different directions from that in which it was originally traveling so that scattering has the effect of diminishing the intensity of light along a given path. Absorption, which results when light energy is converted into rotational, vibrational or thermal kinetic energy, occurs at certain specified wavelengths depending on the absorbing molecule. Absorption and scattering must both be considered in any attempt to predict what the complete atmospheric attenuation will be for a beam of light of a given wavelength. Since molecular density and aerosol concentration change with altitude, these factors must also be taken into consideration.

The AFCRL atmospheric attenuation model develops and tabulates aerosol, Rayleigh, and ozone attenuation coefficients for 22 wavelengths from .27 microns in the ultraviolet through four microns in the infrared, including many wavelengths in the visible spectrum. The AFCRL report in which these tables appear also contains formulas for calculating: 1) the transmission of the atmosphere in a horizontal direction at any altitude, 2) its transmission along a vertical path from a given altitude to any other altitude, and from any altitude to infinity, and 3) its transmission along slant paths in any direction. The AFCRL atmospheric attenuation model fills an essential need for basic research and applied problems in atmospheric physics.

In addition to AFCRL's atmospheric attenuation model, important theoretical studies are being conducted by AFCRL contractors to determine the optical relationship between multiple molecular scattering and aerosol scattering. This work has resulted in a three-volume compilation of data, "Tables Related to Light Scattering in a Turbid Atmosphere" (AFCRL-65-710). To have reached this state of analysis represents considerable progress since the numerical solution of multiple molecular scattering has only recently been available. The mathematics of molecular-aerosol scattering interactions are very complex and solutions must be based on approximations.

One approach to this difficult problem is to consider the light as corpuscular energy instead of a wave. One then follows light photons along their path through the atmosphere including the many scattering—or collision—processes with air molecules or aerosol particles. By so following the history of a great number of photons one can obtain



During the night there is a marked decrease in the aerosol content of the atmosphere, as seen in this chart which covers an eight-hour period.

the light flux in any direction in any type of atmosphere. Such calculations are made by computers. As computer inputs, however, one needs accurate observational data. Thus the measurement of both aerosol distribution and the distribution of optical radiation in the atmosphere is necessary for confirmation or modification of these mathematical solutions.

INFRARED RESEARCH

Much of the Optical Physics Laboratory's infrared research program was included in the foregoing section on Transmission and Background Radiance. This section covers those Laboratory programs that relate to the infrared more specifically. This infrared research is concerned with the fundamental mechanisms of infrared emission

and absorption—and, in particular, infrared emission and absorption by those atmospheric molecules that degrade signal-to-noise ratios of Air Force operational infrared systems. This research is also designed to provide a theoretical base for interpreting the results of various observational programs and to uncover improved spectroscopic devices, sensors, and techniques.

The Laboratory places heavy emphasis on the advancement of spectroscopic techniques and equipments. It is a leading research center in Fourier transform spectroscopy, a relatively recent branch of spectroscopy in which computers are used to obtain high resolution spectra from interferograms.

Also covered in this section are the Laboratory's two observational programs in which infrared instrumentation was carried aboard rockets and missiles. One of these programs is designed to obtain a more precise definition of the infrared horizon in order to improve the performance of horizon sensors used for stabilizing earth-orbiting satellites. The other infrared observational program is one in which sensors were placed near the exhaust nozzles of missiles to observe the efficiency of fuel consumption and to learn something of the characteristic infrared signatures of various fuels and missile plumes.

CHEMILUMINESCENT MECHANISMS: Airglow, the faint luminescence of the sky seen on a dark, clear night, is the best example of chemiluminescence. Sky luminescence is also strongly induced by nuclear detonations in the atmosphere. When optical detectors are used to detect targets, such luminescence, either natural or induced by nuclear detonation, represents so much background noise. Airglow extends from the visible well into the infrared region of the spectrum.

Apart from military interest, measurements of airglow emissions in the infrared can yield a great deal of information about the condition of the atmosphere—for example, its chemical and radiative properties and its ion concentrations. To extract this type of information from emission spectra, accurate knowledge of the dipole moment functions of the molecules of interest is required and is presently unavailable.

A molecule without a dipole moment —that is, a molecule without opposing charges at two points—does not absorb or radiate energy. Most data on dipole moments have been derived from absorption measurements. These data do not adequately describe molecules in high vibrational states. To derive such descriptions, emission spectra measurements of highly excited molecules were made in the Laboratory.

These experiments involve chemical reactions causing chemiluminescence. Following certain reactions, large amounts of energy are sometimes released into vibrational and rotational states of the product molecules. Some of the more important reactions leading to chemiluminescence studied by the Laboratory are:

$$H + O_3 \rightarrow OH + O_2$$
$$NO + O + (M) \rightarrow NO_2 + (M)$$
$$NO_2 + O \rightarrow NO + O_2$$
$$N + NO_2 \rightarrow N_2O + O$$
$$N + NO_2 \rightarrow NO + NO$$

All of these reactions leave the products vibrationally excited, and from analysis of their infrared emission spectra the dipole moments of OH, NO_2, NO and N_2O can be determined.

Another process which may be used to obtain highly vibrationally excited molecules is called "vibraluminescence," and consists of transfer of vibrational energy from a molecule which cannot

radiate (due to lack of a dipole moment) to a molecule which can radiate. Here are some of the processes:

$$N_2^{\ddagger} + CO \rightarrow N_2 + CO^{\ddagger}$$

$$N_2^{\ddagger} + CO_2 \rightarrow N_2 + CO_2^{\ddagger}$$

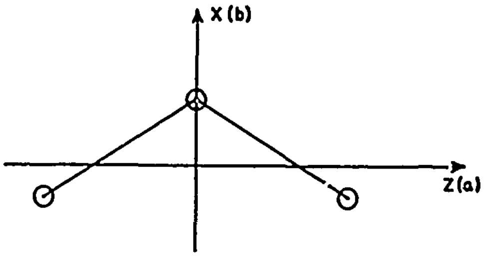
$$N_2^{\ddagger} + N_2O \rightarrow N_2 + N_2O^{\ddagger}$$

$$O_2^{\ddagger} + NO_2 \rightarrow O_2 + NO_2^{\ddagger}$$

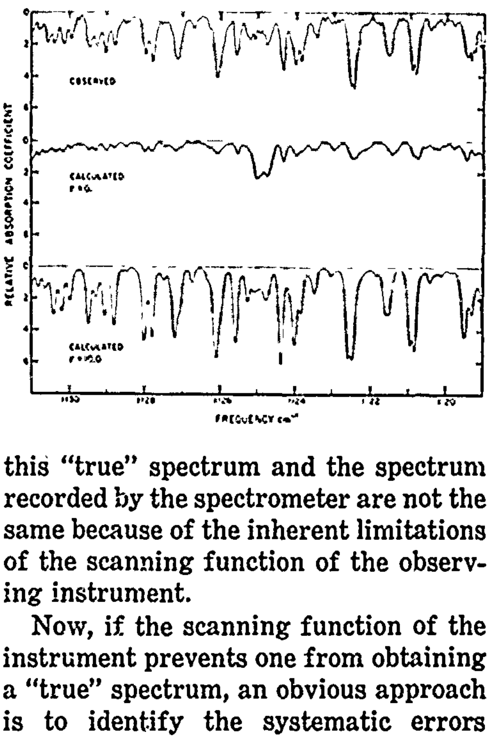
In these processes, large amounts of vibrational energy are transferred from N_2 and O_2 to CO, CO_2, N_2O and NO_2, providing continuous sources of these molecules in a highly excited state.

INTERPRETING EMISSION SPECTRA: It would be reasonable to suppose that, given the infrared emission spectra of a particular molecule, the spectroscopist could derive information on the molecule's vibrational state, rotational energy and dipole moment functions. This is a goal, but the problem has great complexity and complete solutions are distant. Nevertheless, AFCRL scientists, using a computer, have had considerable success interpretating one molecule parameter, the dipole moment. The results have encouraged them to believe that the dipole moment functions of most of the important atmospheric molecules can be readily determined to high accuracy.

Some of the aspects of the overall interpretation problem are these: The vibration-rotation spectrum of any molecule consists of a number of partially overlapped vibrational bands, where each band is the result of the molecule making transitions between two vibrational states. Superimposed on each vibrational state are a large number of rotational energy levels, causing each vibrational band to be made up of a large number of rotational lines. But



The geometry for the three-atom ozone molecule shown above seems simple enough. But when one sets out to calculate mathematically the rotational-vibrational energy states that give rise to its infrared spectra, one is faced with a mathematical task of great complexity. The chart below gives the observed and calculated spectra of ozone.



this "true" spectrum and the spectrum recorded by the spectrometer are not the same because of the inherent limitations of the scanning function of the observing instrument.

Now, if the scanning function of the instrument prevents one from obtaining a "true" spectrum, an obvious approach is to identify the systematic errors in the instrument. In the absence of other objective standards, AFCRL compared experimental spectra against theoretically calculated spectra. By convolving the instrument scanning function with a theoretically calculated spectrum it is possible to match experimental spectra with theoretical spectra

by adjusting the values of the vibrational band strengths (derivable from the dipole moment function) to obtain a best fit.

Despite the complexity of the technique and the requirement for a computer to manipulate the various parameters, AFCRL had demonstrated its soundness. The technique has not only helped in the interpretation of experimental spectra, but has also uncovered weaknesses in existing theoretical models. These models have turned out to be indequate for describing the intensity of infrared emissions observed in the Laboratory. According to these observations, the emissions observed are due to hot (5000–10,000 degrees K) vibrationally excited molecules with low rotational temperatures (300 degrees K). The theoretical description of the radiation, resulting from transitions originating from the upper vibration levels, yields intensities which are too low to account for the observed data. The difficulty is attributed to the Einstein transition probabilities.

In another step to improve the description of the Laboratory data, the Taylor series expansion of the dipole moment function was replaced by another expansion more appropriate to the form of the potential function describing the nuclear separation. Calculations for the Morse oscillators have been carried out using an exponential series expansion of the dipole moment function. The results obtained for carbon monoxide molecules give good agreement with the Laboratory observations. The calculations are under way for extending the work to include such molecules as NO, NO^+ and OH.

ELECTRON EXCITATION: Electron excitation is the third mechanism—the other two being vibration and rotation—whereby atmospheric gases absorb and emit energy. When a molecule absorbs energy it is boosted to a higher energy state; energy is emitted when the electron returns to its ground state. The Optical Physics Laboratory, during the reporting period, investigated the optical radiation from atmospheric gases bombarded by electrons at energies up to 60 keV.

The relative emission of nitrogen and air was measured at various combinations of electron energy and target gas pressure in the wavelength region 2000 to 10,000 angstroms. Absolute fluorescence efficiencies of the 3914 angstrom band of N_2^+ were determined for electron energies from ten to 60 keV at gas pressures ranging from 20 to 800 torr. An absolute cross section for production of N_2^+ first negative (0–0) band at 3914 angstroms by electron impact was measured. In addition, the rotational temperature of N_2^+ (3914 angstroms) was measured as a function of gas pressure.

Other experiments have determined excitation cross sections for certain transitions (notably the 0-0, 1–0, and 2–0 bands of the Meinel system of N_2^+), and collisional deactivation cross sections of N_2^+ for these bands of the Meinel system. In a series of more recent experiments, the radiative lifetimes of these bands of the Meinel system have also been investigated and measured.

Other experiments involving excitation of nitrogen by low energy electrons resulted in measurement of the effective rotational temperature of N_2^+ (3914 angstroms) as a function of electron energy, for energies from 19 eV to 300 eV. Experiments are presently underway to measure the vibrational excitation cross sections of atmospheric molecules excited by low energy (1–10 eV) electrons.

FOURIER TRANSFORM SPECTROSCOPY: The indispensable instrument of optical

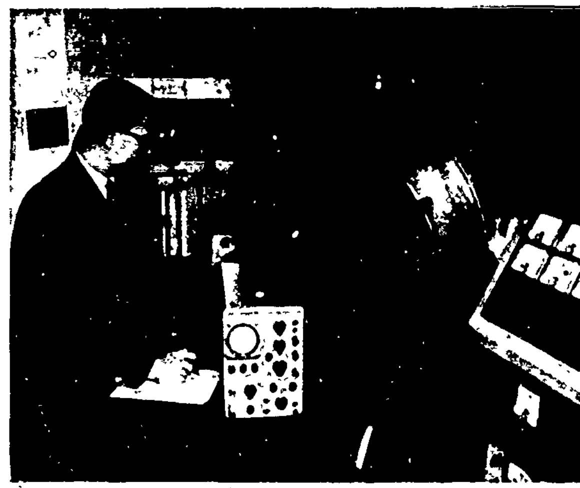
physics research—and physics research in general for that matter—is the spectrometer. A spectrometer shows how the intensity of radiation varies with its frequency. The type of spectrometer that gives the highest resolution is the two-beam interferometer with variable path difference.

In the papers listed at the conclusion of this chapter, a high proportion are seen to deal with Fourier transform spectroscopy, a technique for determining a spectrum by mathematical transformation of the interferometer output. Fourier spectroscopy was first introduced in the early 1950's, and in the intervening years, the technique has seen increasing use in infrared research laboratories, in astronomical observatories, and in instrumentation flown on rockets, balloons, and satellites.

Many researchers in several laboratories have brought the technique to its present state of the art. AFCRL has been a major contributor to this advancement. The most important of these contributions, one made in the late 1950's, was the development of the lamellar grating, a wavefront dividing interferometer for use at very long infrared wavelengths. Another AFCRL development is the use of an analog computer, instead of the digital computer conventionally used for processing the interferometer data.

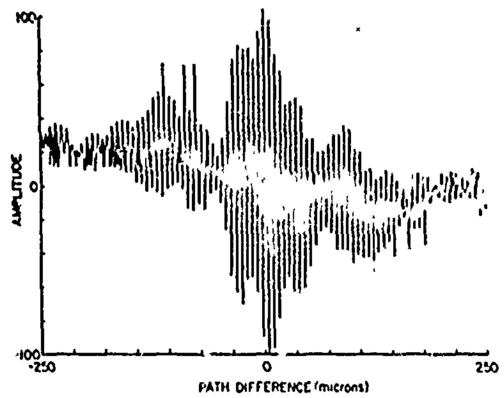
Work during the reporting period was concentrated on better methods for transforming interferograms to spectra. Errors which can occur due to improper truncation of the interferogram have been studied. It was found that the Hilbert transform was useful in describing some of these. The general problem of transforming asymmetric interferograms, asymmetrically truncated, was studied in detail.

Also during the reporting period, two far infrared Fourier spectrometers were built. These were a Michelson interferometer and a lamellar grating interferometer. Both instruments are mounted in vacuum tanks, and employ a liquid helium cooled germanium bolometer. The Michelson interferometer has double beam optics attached for the simultaneous measuring of a sample and reference interferogram, doubling the efficiency of the instrument and at the same time increasing its precision. The lamellar grating interferometer is equipped with a multiple pass absorption cell capable of a maximum path length of ten meters for studies of gaseous absorption.

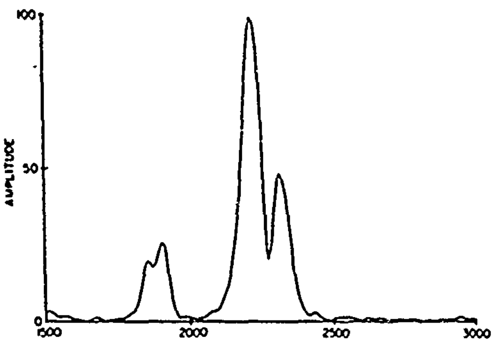


Gases absorb energy by electron excitation as well as by vibration and rotation mechanisms. In this cylindrical chamber, AFCRL measures the relative emission of gases at different combinations of electron energy and gas pressure.

MOLECULAR BEAMS: Most chemical reactions, whether in gas or in liquid, take place within an energy range of less than ten electron volts. The generation of high fluxes of atoms and molecules in this energy range has presented many technical difficulties. But the realization of such generators capable of producing fluxes of 10^{15} particles per



Transform spectroscopy (discussed in the associated text) involves transforming an interferogram of the type shown above (of an N+NO reaction) to its spectrum shown below.



square centimeter per second or higher would provide the scientist with a powerful new research instrument. He could investigate processes in the laboratory that were heretofore impossible to observe with precision. The Optical Physics Laboratory is interested in such generators for studying high velocity molecular collisions that result in visible and infrared radiation.

During this reporting period, the Laboratory undertook a substantial effort to design and build molecular beam accelerators. Three methods of beam production have been pursued, two of which originated within the Laboratory. One of these is the charge exchange molecular beam system in which a curved magnetic field is employed to keep ions and electrons together and thus overcome the severe problem of space charge spreading. Beams of 2 eV argon atoms with an intensity of 10^{14} particles per square centimeter per second have been produced by equipments based on this technique.

The second technique is simple in concept. It consists of firing a rifle bullet (which has been hollowed and filled with gas) into a vacuum chamber. The bullet is split by a knife edge after it reaches terminal velocity. The two halves of the bullet are deflected away allowing the gas to travel on as a molecular beam. The technique, if successful, should provide unparalleled intensities. Such a generator is now (June 1967) being fabricated.

The third technique is the supersonic nozzle method which was originally suggested by Kantrowitz and Grey in 1951, and which has been investigated in several countries. It converts the internal energy of the gas into forward translational energy after the isentropic expansion through a miniature nozzle. By heating the nozzle and seeding the light "carrier" gas with a heavy gas, high energies and intensities can be achieved. The large dynamic pumping system required for beam production in this manner has already been designed, purchased and installed.

INFRARED HORIZON STUDY: Infrared instruments for sensing the earth's horizon are basic to satellite attitude control. More than 25 varieties of infrared horizon sensing instruments are currently in the space program inventory. The effectiveness of earlier systems was limited by inaccuracies and instabilities caused by infrared horizon anomalies. Most of the difficulties experienced in orbit can be traced to a lack of knowl-

edge of the radiating characteristics of the horizon as viewed from a space vehicle.

During the reporting period, AFCRL launched three Aerobee rockets, all from White Sands, New Mexico, to obtain a more accurate description of the earth's limb radiance. The instruments and operating procedure of all three rockets were the same. The payloads in each rocket consisted of an infrared radiometer equipped for measurements in three different spectral regions and stellar mappers for fine attitude determination. More than 200 observations of the horizon were obtained on each flight.

Observations of particular interest were those made in the 15 micron CO_2 region and the 20 micron water vapor region. From the three successful flights, the Laboratory determined that the 15 micron region provides a stable reference free from cloud effects and is generally free from the large fluctuations observed in other regions.

During the reporting period, this molecular beam generator, using the supersonic nozzle technique, was installed at AFCRL. It is designed to produce a dense flux of atoms and molecules in an energy range of less than ten electron volts. Most chemical reactions take place in this energy range.

MISSILE PLUME MEASUREMENTS: During the reporting period, the Laboratory placed spectrometers and radiometers aboard five missiles launched from Cape Kennedy to study the optical characteristic of missile exhausts. Instruments were placed in special pods aboard three Centaurs, an Atlas, and a Saturn Apollo. The pods were physically mounted on the missile in such a way as to obtain an unobstructed view of the engine's exhaust plume.

The missile instrumentation had several purposes. One, was to obtain infrared signatures of the missile plume. Another, was to determine the efficiency of fuel consumption. The test procedures, worked out by AFCRL in the early 1960's, have been used to observe the plumes of many Air Force and NASA missiles since that time.

The AFCRL instrument pod contains two multi-channel radiometers, one high resolution spectrometer, and a dropout capsule. This dropout capsule, as the name implies, is designed to be ejected directly into the missile plume so that simultaneous measurements can be made from both inside and outside the plume. The capsule is about ten inches in diameter and four feet in length and is ejected from the main instrument pod at an altitude of about 150 kilometers. It has a self-contained power and telemetry system. Plume measurements of all five missiles covered the spectrum between 0.5 and 4.5 microns.

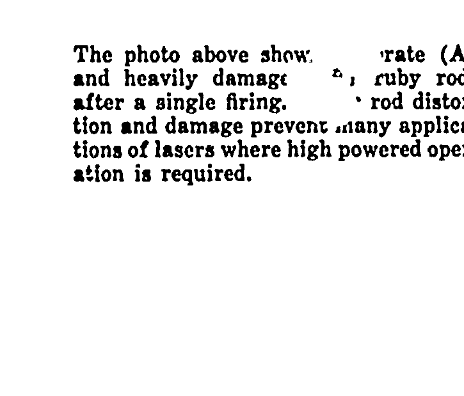
LASER PHYSICS

The Laboratory's laser physics program is conducted to develop a better understanding of lasers, to uncover new effects, and to predict the ultimate capabilities of lasers.

This payload assembly was designed to obtain a more accurate description of the earth's infrared horizon. Such an assembly was carried aboard three rockets.

In the solid state laser area primary emphasis is placed on ruby. Ruby appears to be one of the best laser materials presently available for use in future operational laser equipments for high repetition rate target illumination, and for many other potential Air Force systems.

To realize high power operational laser devices, the efficiency of the ' ...sic



The photo above show. ·rate (A) and heavily damag ..., ruby rods after a single firing. · rod distortion and damage prevent many applications of lasers where high powered operation is required.

c mponent of the laser—the laser rod—must be improved. During the reporting period, the Laboratory studied various loss mechanisms, with special attention being given to the compensation of optical distortions that occur in the laser rod when it is energized.

Apart from this research, the Laboratory undertook an extensive literature survey of the applications that have been made of lasers. This survey was published as an in-house report, "A Bibliography of Laser Applications" (AFCRL-67-0223). The bibliography contains 644 entries from the open literature published during the period 1961 through 1966 and covers such areas of applications as mechanical measurements and standards, communications, optical signal processing, interferometry, metal working and chemistry.

Also discussed in this section is a nonlaser technique for generating high intensity, incoherent light. This research involves a highly efficient arc lamp that may be used in high speed photography and in an incoherent optical radar.

LASER THEORY: Theory has many aims. It can describe a particular experimental result. It can be used to predict new effects. It can be used as a check on the reliability of an ad hoc approach. But basically it gives a fundamental understanding of what's going on. A theory should be based on all irreducible constituents. But no theory of a complicated system like the laser can start with really irreducible constituents. The development of laser theory can proceed only through approximations.

By way of illustration, one may wish to deduce from theory the linewidth of the radiation of a given excited crystal. An irreducible constituent are the atoms

in the crystal which radiate spontaneously from an excited state. If only this constituent is considered, the answer would be approximate because the linewidth of the resultant radiation is also influenced by the lattice vibrations in the host crystal. To consider both the spontaneously radiating atoms and lattice vibrations, the theory would become much more complicated. In fact this more fundamental form of solid-laser theory has not yet been made. (Gas lasers would have a different set of interrelating constituents.) If the more fundamental form of solid-laser theory were developed, however, it might possibly reveal some interesting new effects.

Another example of weakness in the present state of laser theory concerns electromagnetic modes of the laser resonator. These modes have been measured with considerable precision and must be included as one of the irreducible constituents in existing fundamental laser theories. In dealing with certain laser problems, the manner of their inclusion is entirely satisfactory. In certain studies conducted at AFCRL, these same theories are lacking in that they do not permit the correct treatment of the time-variation aspects of laser coherence and threshold behavior. Thus, they are less than fully satisfactory.

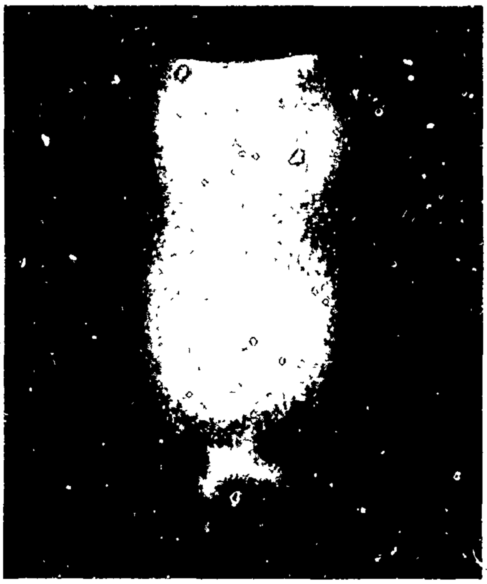
One strategy for overcoming the difficulties of formulating a fundamental laser theory is to make contact with other, thoroughly studied, bodies of theory. During the present reporting period AFCRL borrowed and applied certain constructs from the kinetic theory of gases and plasmas and from theories of superfluids.

The goal of the first line of work is to construct and compare kinetic equations for various types of lasers by drawing upon the long experience with similar equations developed in the kinetic theory of gases dating back to Boltzmann in the last century. In addition to describing the light energy output and phase relations in lasers, such equations contain information on the statistical distributions of the active atoms and of the light. It is important to know the statistical distribution of the light since it determines the ultimate limitations on the use of lasers for communication and ranging.

The second line of work has demonstrated an unexpectedly exact correspondence between basic aspects of superfluidity theory and characteristic properties (both macroscopic and microscopic) of lasers. This work has a diversity of consequences. One is a new necessary condition for laser coherence which has already proved useful in the analysis of a class of devices. Another is the clarification of the relationship between those laser theories that assume a definite phase for the laser light and those that do not. Still another is the prediction of a new macroscopic effect, the analog of Josephson tunneling between superconductors.

BRIGHTNESS ENHANCEMENT: A prime characteristic of a laser light source is brightness. A high brightness laser implies being able to concentrate large amounts of power in a small spot on a target at a large distance away; it is defined as the power per square centimeter in a beam divided by the square of its divergence angle. Ruby lasers are theoretically capable of developing a brightness 1000 times greater than that which has been achieved.

The reason for this reduced brightness has been made clear by research done by AFCRL over the past three years. Basically, the cause is the optical distortion in the laser rod. This distortion may be a permanent distortion (having occurred during the growth of



The anode of the AFCRL-developed Nanolite exhibits a curious jet after firing. This jet appears to be electrode material ejected explosively. The jet as it appears 30 nanoseconds (above) and 80 nanoseconds (below) after firing is shown.

the crystal) or it may be induced during pumping due to the non-uniform absorption of pump energy. The distortion leads to excitation of electromagnetic modes with large divergence compared to a simple plane wave. Thus, the brightness is several orders of magnitude lower than it could be compared to the case of plane waves being emitted from the end of the laser rod.

INCOHERENT OPTICAL RADAR: A short range, incoherent optical radar system, having a number of advantages over laser devices, was demonstrated during the period. This system, which uses a small but extremely intense arc-lamp called the Nanolite, was successfully tested on targets 100 feet away. A more sophisticated version may be able to detect and range objects as far away as 1500 feet, with an accuracy of a few feet. Basically, the system consists of the Nanolite, a collimating lens, a photoelectric detector, and an electronic timing device.

The optical radar system offers a number of advantages over both conventional and laser radars for short range applications. The primary advantages are its small size, low power requirements, low cost and ruggedness. The operating characteristics of the system also offer advantages for short range optical radars. One of these characteristics is a rapid pulsing capability. The Nanolite is capable of firing up to 10,000 evenly spaced pulses of high intensity light per second. This pulsing capability is inherent in the device itself and does not require any external pulsing system. The Nanolite also has a broad beam, making target acquisition much easier.

The Nanolite is the brightest non-laser light source yet developed. Its most intense flashes have a brilliance

exceeding 30 million candles per square centimeter, produced by passing thousands of amperes through an arc channel a tenth of a millimeter in diameter. However, the duration of these flashes is so short (a few nanoseconds, or billionths of a second) that very little electrode heating and erosion occur, giving the Nanolite a long lifetime. Both the Nanolite and the unique inductance-free coaxial capacitor used to store energy for discharge through the arc channel were developed at AFCRL.

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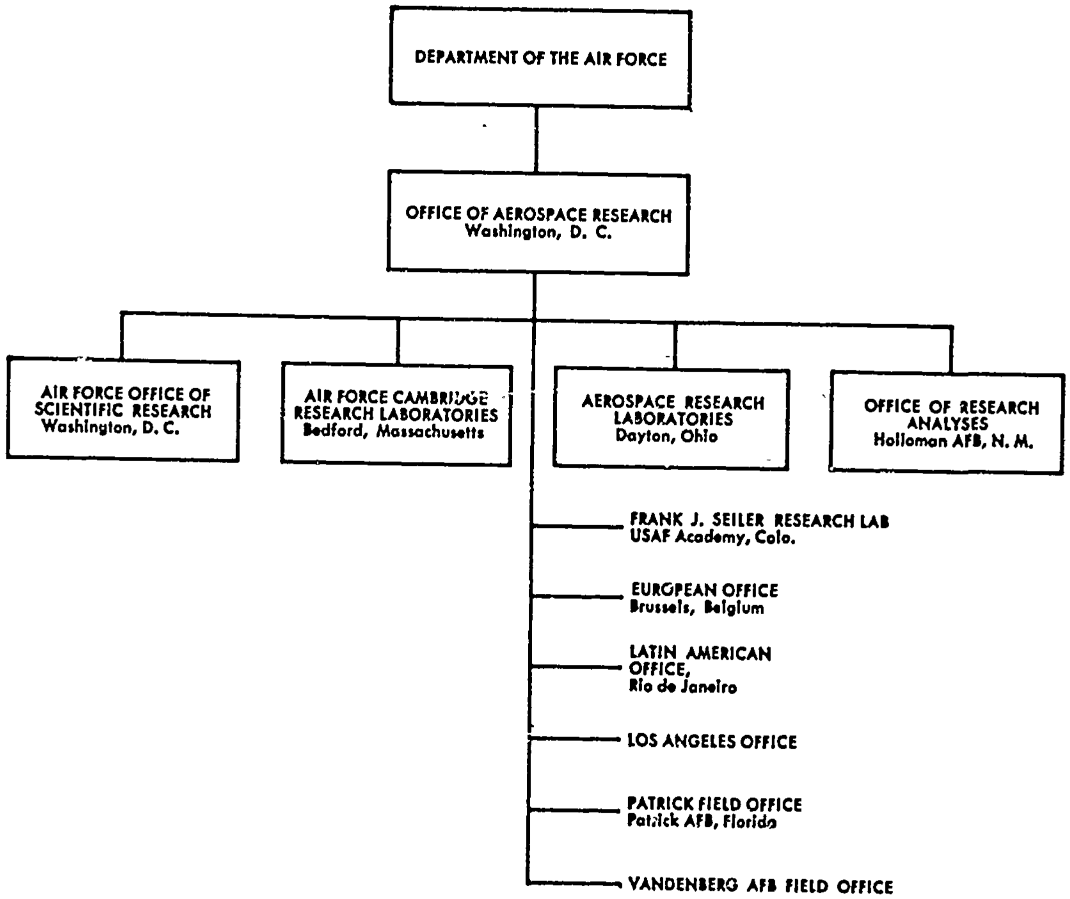
Appendix A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CRMXP	Technical Photography	C. Rodberg
CRMXR	Publications	J. Marple
CRMXS	Experimental Support	A. Cate

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Assistant Deputy	J. J. Brady

CRSA ADMINISTRATIVE MANAGEMENT DIVISION

Chief		J. M. Linda
CRSAM	Mail Distribution	R. R. Wagner
CRSAR	Records Management	J. E. Cavanagh
CRSAS	Security	G. J. Cody
CRSAT	Travel	B. Barron

CRSP PERSONNEL MANAGEMENT DIVISION

Chief		J. P. Cushman
CRSPC	Management Services	F. Marelli
CRSPM	Military Personnel	SM Sgt O. Harris
CRSPP	Procedures	J. V. Ierardi

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AFCRL Laboratories

CRG
COMMANDER
COL R. F. LONG
VICE COMMANDER
COL O. J. KVAMME

CRB	DATA SCIENCES LABORATORY	
Director		R. M. Alexander
Senior Scientist—Computer Sciences		H. Zschirnt
CRBA	Applied Mathematics	R. H. Urbano
CRBD	Logic Technology	M. E. Bronking
CRBG	Synthetic Coding	J. C. Mott Smith
CRBI	Dynamic Processes	C. M. Walter
CRBK	Information Theory	C. F. Hobbs
CRBS	Digital Speech Compression	C. P. Smith
CRBV	Speech Research	W. Wathen Dunn

CRD	MICROWAVE PHYSICS LABORATORY	
Director		C. J. Sletten
CRDG	Radiation & Reflection	P. Blacksmith
CRDM	Plasma Electromagnetics	W. Rotman
CRDP	Microwave Acoustics	P. H. Carr*
CRDT	Transmission	E. Altshuler
CRDW	Waves & Circuits	C. J. Sletten*

CRE	AEROSPACE INSTRUMENTATION LABORATORY	
Director		R. M. Slavin
Senior Engineer		C. S. Tilton
Senior Scientist—Design Climatology		N. Sissenwine
Senior Engineer—Meteorological Equipment		A. S. Carten
CREA	Balloon Flight Requirements Analysis	T. J. Danaher
CREB	Balloon Research	T. W. Kelly
CREC	Balloon Instrumentation	C. S. Tilton
CREF	Experimental Balloon Activities	F. X. Doherty
CREH	Balloon Research & Development Test	Lt Col R. C. Clemenson
CREI	Research Probe Instrumentation	C. H. Reynolds
CREK	Research Probe Flight	P. Gustafson
CREN	Meteorological Observing Techniques	W. H. Paulsen
CRER	Vertical Sounding Techniques	R. Leviton
CRES	Direct Sensing Techniques	J. F. Morrissey
CREU	Equipment Engineering and Evaluation	A. S. Carten
CREW	Design Climatology	N. Sissenwine

CRF	SPACE PHYSICS LABORATORY	
Director		Lt Col T. D. N. Douthit
Senior Scientist—Astrophysics		H. K. Sen
Senior Scientist—Auroral Physics		N. J. Oliver
Senior Scientist—Radio Astronomy		J. Aarons
CRFA	Plasma Astrophysics	M. A. Levine
CRFC	Cosmic Radiation	L. Katz
CRFE	Energetics	N. Yannoni
CRFG	Geomagnetism	J. McClay
CRFL	Lunar Planetary Research	J. W. Salisbury
CRFM	Meteor Physics	R. A. Skrivanek
CRFR	Radio Astronomy	J. Aarons
CRFS	Sacramento Peak Observatory Director	J. W. Evans
CRFW	Space Forecasting	Maj R. A. Bena

CRH	METEOROLOGY LABORATORY	
Director		M. L. Barad
Senior Scientist—Heat Transfer		C. N. Touart
CRHA	Weather Radar	K. R. Hardy
CRHB	Boundary Layer	D. A. Haugen
CRHC	Cloud Physics	R. M. Cunningham
CRHD	Dynamics	R. Shapiro
CRHO	Satellite Meteorology	T. J. Keegan
CRHU	Upper Atmosphere	W. S. Hering

CRJ	TERRESTRIAL SCIENCES LABORATORY	
Director		O. W. Williams
Senior Scientist—Wave Propagation		N. A. Haskell
CRJG	Geodesy	O. W. Williams*
CRJL	Gravity	B. Szabo
CRJT	Geotechnics	Capt J. T. Neal
CRJW	Wave Propagation	K. C. Thomson

CRO	OPTICAL PHYSICS LABORATORY	
Director		J. S. Garing
Senior Scientist—Infrared Physics		H. Fischer
CROA	Atmospheric Optics	R. W. Fenn
CROI	Infrared Physics	R. G. Walker
CROL	Laser Physics	C. M. Stickley
CROO	Radiometry	T. P. Condron
CROR	Radiation Effects	H. P. Gauvin

CRU	UPPER ATMOSPHERE PHYSICS LABORATORY	
Director		C. G. Stergis
Senior Scientist—Solar Ultraviolet		H. Hinteregger
Senior Scientist—EM Propagation		P. Newman
Senior Scientist—Ionospheric Physics		W. Pfister
Senior Scientist—Spectroscopy		Y. Tanaka
CRUA	Aurora & Airglow	S. Silverman
CRUB	Atmospheric Structure	K. S. W. Champion
CRUE	Electromagnetic Environment	E. A. Lewis
CRUI	Ionospheric Perturbations	N. W. Rosenberg
CRUR	Ionospheric Radio Physics	L. Toman
CRUS	Spectroscopic Studies	A. Jursa
CRUU	Solar Ultraviolet	H. Hinteregger
CRUZ	Composition	R. S. Narcisi

CRW	SOLID STATE SCIENCES LABORATORY	
Director		R. M. Barrett
Senior Scientist—Lattice Dynamics		J. N. Plendl
CRWA	Advanced Studies	R. M. Barrett*
CRWB	Purification and Growth	C. S. Sahagian
CRWD	Properties and Phenomena	A. Kahan
CRWE	Magnetics and Resonance	E. R. Czerlinsky
CRWF	Semiconductor Physics	C. E. Ryan
CRWG	Device Physics	R. F. Cornelissen
CRWH	Radiation Effects	C. D. Turner

CRZ	WEST COAST OFFICE El Segundo, California	
Chief		G. M. DeGiacomo
Resident Scientist Sunnyvale, California		L. G. Letterman

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Appendix B

AFCRL PROJECTS BY PROGRAM ELEMENT

Program Element	Project Number, Title, and Agency		Lab
6143001F	*IN-HOUSE LABORATORY INDEPENDENT RESEARCH*		
	0000	Laboratory Director's Fund	CRT**
6144501F	*DEFENSE RESEARCH SCIENCES* OAR*		
	5620	Synthesis and Properties of Single Crystal Electromagnetic Materials	CRW
	5621	Physics of Solid State Phenomena	CRW
	5628	Communication Processes	CRB
	5629	Radio Astronomy and Astrophysics	CRF
	5631	Ionospheric Radio Physics	CRU
	5632	Research in Electronic Information	CRB
	5633	Upper Atmosphere Dynamics	CRU
	5634	Research in Optical Physics	CRO
	5635	Electromagnetic Radiation	CRD
	5638	Research in Solid State Electronics	CRW
	7922	Project THEMIS	CRT
	8600	Research on Cosmic Radiation	CRF
	8601	Research in Geomagnetism	CRF
	8602	Lunar-Planetary Spectra	CRF
	8603	Research on Infrared and Optical Techniques	CRO
	8604	Meteorological Research	CRH
	8605	Upper Atmosphere Structure	CRU
	8607	Basic Research in Geodesy and Gravity	CRJ
	8608	Research on Plasma Dynamics for Application to Astrophysics	CRF
	8617	Electrical Structure of Aerospace	CRU
	8620	Research on Cloud Physics	CRH
	8623	Geologic Properties: Minerals, Landforms and Crust	CRJ
	8627	Spectroscopic Studies of Upper Atmosphere Processes	CRU
	8635	Research on Physical Processes	CRF
	8647	Research on Magnetohydrodynamics and Space Physics	CRF
	8654	Aerospace Geodesy	CRJ
	8658	IR Non-Equilibrium Radiative Mechanisms	CRO
	8659	Energetics Processes Research	CRF
6154501D	*DEFENSE RESEARCH SCIENCES* ARPA		
	8668	Bilateral Communications Between Men and Machines Through Conversation (Order #627)	CRB
	8672	Methods of Formal Reasoning by Machine (Order #700)	CRB
	8673	Participation in and Development of Programming Language for the M44 Computer Time-Sharing System (Order #696)	CRB
	8684	Research on On-Line Computation (Order #865)	CRB
	8687	Unconventional Solid State Materials and Devices (Order #1060)—Project THEMIS	CRW
6240527F	*AEROSPACE AVIONICS* AFSC—AFAL		
	4608	Physics of Radiation-Resistant Solid State Materials and Devices	CRW
	4645	Coherent Optical Device Physics	CRO

6240539F	*ENVIRONMENT*	AFSC—OAR	
	4062	Electromagnetic Wave Propagation in Dynamic Situations	AFAL
	4603	Long Wave Propagation and Ionospheric Interactions	CRU
	4642	Interaction of Electromagnetic Radiation with Ionized Flow Fields	CRD
	4643	Radio Astronomical and Satellite Studies of the Atmosphere	CRF
	4691	Aeronomical Kinetics	CRU
	5579	Electromagnetic Propagation Techniques	RADC
	6020	Aircraft Meteorological Sensors and Techniques	CRE
	6670	Atmospheric Sensing Techniques	CRE
	6672	Weather Radar Techniques	CRH
	6687	Aerospace Composition	CRU
	6688	Aerospace Radiation	CRU
	6690	Aerospace Density	CRU
	6698	Satellite Meteorology	CRH
	7600	Geodesy for Naviguidance	CRJ
	7601	Electric and Magnetic Fields	CRF
	7605	Weather Modification	CRH
	7621	Atmospheric Optics	CRO
	7628	Terrestrial Geology	CRJ
	7635	Upper Atmosphere Chemical Physics	CRU
	7637	Air Pressure Pulse	CRJ
	7639	Elastic Wave Propagation Studies	CRJ
	7649	Solar Environmental Effects	CRJ
	7655	Micrometeorology	CRH
	7659	Aerospace Research Instrumentation	CRE
	7661	Aurora and Airglow	CRU
	7663	Ionospheric Characteristics	CRU
	7667	Meteor Physics	CRF
	7670	Geophysical Effects on Infrared Radiation	CRO
	8624	Variability of Meteorological Elements	CRE
	8628	Free Air Circulations	CRH
	8666	Space Environment Observing and Forecasting Techniques	CRF
	8679	Contrail Mechanics	CRF
	8682	Millimeter-Wave Propagation Research	CRD
6240545F	*GROUND ELECTRONICS*	AFSC—RADC	
	4600	Electromagnetic Radiation Techniques	CRD
	4610	Information Processes for Communication	CRB
	4641	Advanced Data Processing Technology	CRB
	4648	Methods for Processing Complex Information	CRB
6250301D	*DEFENDER*	ARPA	
	4406	Ionization in Missile Trails (Order #234)	CRU
	6327	Re-Entry Vehicle Instrumentation (Order #254)	CRO
	8662	Optical Target Measurements (Order #363)	CRO
	8663	Optical Techniques (Order #450)	CRO
	8671	ECM Antenna Studies (Order #693)	CRD
	8671	High Pressure Static Shear Tests (Order #693—Task 6)	CRJ
	8675	Reduction of Radar Cross Section by Impedance Loading (Order #803)	CRD
	8680	High Altitude Tethered Balloon (Order #755)	CRE
6250601D	*VELA*	ARPA	
	8652	Seismic Research Project VELA UNIFORM (Order #292)	CRJ
	8669	Magnetohydrodynamic Wave Propagation in the Ionosphere (Order #635)	CRU

6441506F	*OTHER OPERATIONAL SUPPORT*			AFSC	
	1559	1559-34	Cricketsonde Systems	ASJ	CRE
	1559	1559-85	Balloon Puncturing Device	ASJ	CRE
	1559	1559-108	Covert Ceiling/Wind Measuring Unit	ASJ	CRE
	1559	1559-114	Solid State Wind Measuring Set	ASJ	CRE
	4051	T-405102	Site Monitoring	AFWL	CRJ
	5003	Refractive Index Sounding System		ESD	CRE
6540212F	*ENVIRONMENTAL RESEARCH SUPPORT*			OAR	
	6665	Plastic Balloon Components and Techniques			CRE
	7043	Aerospace Research Support Program (ARSP)			CRT
6540215F	*TEST INSTRUMENTATION*			AFSC—ESD	
	6682	Test Range Meteorological Support			CRE
6164601H	*DASA*				
	5710	NWET			CRE, O, T&U
6550301H	5710	NWER			CRU, O, W

* Denotes Agency Having Management Responsibility for Program Element

** See Organization Chart, Appendix A, for Laboratory Title

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Appendix C

AFCRL ROCKET AND SATELLITE PROGRAM: JULY 1965 - JUNE 1967

Date	Launch Site	Vehicle	Experiment	Scientist	Results
7 Jul 65	CHILL	Aerobee 150	Meteor Dust Collection	R. Soberman	Failure
14 Jul 65	CHILL	Aerobee 150	Meteor Dust Collection	R. Soberman	Failure
17 Jul 65	APGC	Nike Apache	Electromagnetic Absorption	R. Harvey	Failure
21 Jul 65	WSMR	Aerobee 150	Mass Spectrometers (2)	R. Narcisi	Partial
			Impedance Probe	J. Ulwick	Failure
21 Jul 65	APGC	Niro	Atmospheric Density	G. Faucher	Success
			Vehicle Dynamics	C. Hoult	Partial
24 Jul 65	CHILL	Aerobee 150	Noctilucent Clouds	R. Soberman	Failure
12 Aug 65	WSMR	Aerobee 150	Extreme Ultraviolet Monochromator	H. Hinteregger	Success
17 Aug 65	WTR	Agena PB	Cosmic Radiation (Nuclear Emulsions)	R. Filz	Success
21 Aug 65	ETR	Gemini Titan 5	Radiometric Measurements	J. Lovett	Success
25 Aug 65	ETR	Thor Delta (OSO-C)	Extreme Ultraviolet Monochromator	H. Hinteregger	Failure
26 Aug 65	APGC	Aerobee 150	Gyro Resonance	J. Ulwick	Partial
2 Sep 65	WTR	Thor Agena	Satellite-to-Satellite Communications	M. Wong	Failure
			Exospheric Radiation	J. Aarons	Failure
			Radio Noise	J. Ulwick	Failure
			IR-UV Optical Measurements	L. Block	Failure
16 Sep 65	APGC	Black Brant V	Vehicle Test	C. Hoult	Success
22 Sep 65	WTR	Agena	Cosmic Radiation (Nuclear Emulsions)	R. Filz	Success
24 Sep 65	WSMR	Aerobee 150	Infrared Horizon Measurements	C. Cunniff	Partial
			Airglow Measurements	C. Cunniff	Success
5 Oct 65	WTR	Atlas Pod	Gaseous Composition	R. Narcisi	Success
			VLF Receiver Group	P. Newman	Success
			60 Cycle Probe	P. Newman	Success
14 Oct 65	WTR	Thor Agena (OGO-II)	Extreme Ultraviolet Spectrophotometer	H. Hinteregger	Partial
15 Oct 65	ETR	OV2-1	Cosmic Radiation	L. Katz	Failure
17 Oct 65	Ft. Wainwright, Alaska	Niro	Auroral Ionosphere	J. Ulwick	Success
21 Oct 65	Ft. Wainwright, Alaska	Niro	Auroral Ionosphere	J. Ulwick	Success
2 Nov 65	APGC	Exos	Atmospheric Density (7" Falling Sphere)	A. Faire	Failure
3 Nov 65	WSMR	Aerobee 150	Extreme Ultraviolet Monochromator	H. Hinteregger	Success
3 Nov 65	APGC	Nike Cajun	Atmospheric Density (7" Falling Sphere)	A. Faire	Success
9 Nov 65	WSMR	Aerobee 150	Lunar Infrared Measurements	J. Salisbury	Failure
9 Nov 65	WSMR	Aerobee 150	Extreme Ultraviolet Monochromator	H. Hinteregger	Success

CHILL — Fort Churchill, Canada
APGC — Air Proving Ground Center, Eglin AFB, Florida
WSMR — White Sands Missile Range, New Mexico
ETR — Eastern Test Range, Cape Kennedy, Florida
WTR — Western Test Range, Vandenberg AFB, California

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AFCRL ROCKET AND SATELLITE PROGRAM: JULY 1965 - JUNE 1967

Date	Launch Site	Vehicle	Experiment	Scientist	Results
10 Nov 65	APGC	Nike Cajun	Mass Spectrometer	R. Narcisi	Failure
			Ion Trap	R. Sagalyn	Success
16 Nov 65	APGC	Nike Cajun	Mass Spectrometer	R. Narcisi	Success
			Ion Trap	R. Sagalyn	Success
17 Nov 65	APGC	Nike Cajun	Mass Spectrometer	R. Narcisi	Success
			Ion Trap	R. Sagalyn	Success
17 Nov 65	APGC	Nike Cajun	Ionospheric Winds and Temperatures	N. W. Rosenberg	Success
18 Nov 65	APGC	Nike Cajun	Mass Spectrometer	R. Narcisi	Failure
			Ion Trap	R. Sagalyn	Failure
18 Nov 65	APGC	Nike Cajun	TMA Trail (Project Redlamp)	N. W. Rosenberg	Success
18 Nov 65	APGC	Nike Javelin	TMA Release Up—Na Release Down	F. Marcos	Success
4 Dec 65	ETR	Gemini Titan 7	Radiometric Measurements	J. Lovett	Success
9 Dec 65	WTR	Agena PB	Cosmic Radiation (Nuclear Emulsions)	R. Filz	Success
9 Dec 65	CHILL	Nike Cajun	Atmospheric Density (7" Falling Sphere)	A. Faire	Partial
9 Dec 65	CHILL	Nike Cajun	Atmospheric Density (7" Falling Sphere)	A. Faire	Success
11 Dec 65	CHILL	Nike Apache	Atmospheric Density (7" Falling Sphere)	A. Faire	Partial
11 Dec 65	CHILL	Nike Apache	Atmospheric Density (7" Falling Sphere)	A. Faire	Success
21 Dec 65	ETR	OV2-3	Magnetic Fields	B. Shuman	Failure
			Electrical Structure	R. Sagalyn	Failure
			Cosmic Radiation	L. Katz	Failure
23 Jan 66	CHILL	Astrobee 200	Auroral Measurements (Electrostatic Analyzer and Ion Chamber)	J. Sandock and L. Katz	Failure
28 Jan 66	CHILL	Astrobee 200	Auroral Measurements (Electrostatic Analyzer and Ion Chamber)	J. Sandock and L. Katz	Failure
10 Feb 66	WTR	Atlas Pod	Infrared Radiation Measurements	J. Lovett	Success
18 Feb 66	Puerto Rico	Nike Javelin	Ionospheric Winds (Project Redlamp)	M. MacLeod	Success
19 Feb 66	Puerto Rico	Nike Javelin	Ionospheric Winds (Project Redlamp)	M. MacLeod	Failure
20 Feb 66	Puerto Rico	Nike Javelin	Ionospheric Winds (Project Redlamp)	M. MacLeod	Success
20 Feb 66	Puerto Rico	Nike Javelin	Ionospheric Winds (Project Redlamp)	M. MacLeod	Failure
2 Mar 66	Wallops Island	Aerobee	Extreme Ultraviolet Monochromator	H. Hinteregger	Success
			Retarding Potential Analyzer	H. Hinteregger	Success
3 Mar 66	Wallops Island	Aerobee	Extreme Ultraviolet Monochromator	H. Hinteregger	Partial
			Retarding Potential Analyzer	H. Hinteregger	Success
9 Mar 66	WTR	Agena	Cosmic Radiation	R. Filz	Success
10 Mar 66	APGC	Niro	Atmospheric Density (Bremsstrahlung)	J. McIsaac	Partial
30 Mar 66	WSMR	Aerobee	Extreme Ultraviolet Monochromator	H. Hinteregger	Success
			Retarding Potential Analyzer	H. Hinteregger	Success
30 Mar 66	WTR	OV1-5	UV-Visible-IR Radiation Satellite (3 Radiometers and 2 Interferometers)	J. Lovett	Success
30 Mar 66	WTR	Atlas Pod	Retarding Potential Analyzer	J. Sandock	Success
			Electrical Structure (Spherical Analyzer)	R. Sagalyn	Partial
			VLF Propagation (Receiver Group)	P. Newman	Partial
			50/60 Cycle Radiation	P. Newman	Partial

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AFCRL ROCKET AND SATELLITE PROGRAM: JULY 1965-JUNE 1967

Date	Launch Site	Vehicle	Experiment	Scientist	Results
7 Apr. 66	WTR	Agena	Cosmic Radiation	R. Filz	Success
10 Apr 66	ETR	Atlas Centaur	Centaur Plume Radiation Measurements	J. Lovett	Failure
22 Apr 66	WTR	OV3-1	Proton Measurements	L. Katz	Failure
			Electron Measurements	L. Katz	Partial
			Low Energy Electrons	L. Katz	Success
			Plasma Probes	R. Sagalyn	Success
28 Apr 66	WSMR	Aerobee	Infrared Horizon Measurements	R. Walker	Success
1 May 66	CHILL	Javelin	Magnetic Fields	R. Vancour	Success
			Proton Detector	R. Vancour	Success
			Electron Detector	R. Vancour	Success
24 May 66	WTR	Agena	Cosmic Radiation	R. Filz	Success
4 Jun 66	ETR	OGO-B	Thermal and Epithermal Protons and Electrons	R. Sagalyn	Success
17 Jun 66	APGC	Nike Cajun	Chemical Release	M. MacLeod and D. Golomb	Success
21 Jun 66	WTR	Agena	Cosmic Radiation	R. Filz	Success
23 Jun 66	APGC	Niro	Chemical Release (TMA)	M. MacLeod and D. Golomb	Success
24 Jun 66	APGC	Niro	Chemical Release (Ba Vapor)	D. Golomb	Partial
24 Jun 66	APGC	Niro	Chemical Release (NO)	D. Golomb	Success
25 Jun 66	APGC	Niro	Chemical Release (NO)	D. Golomb	Success
25 Jun 66	APGC	Niro	Chemical Release (Ba Vapor)	D. Golomb	Partial
26 Jun 66	Norway	Nike-Apache	50/70 Cycle Probe	P. Newman	Success
28 Jun 66	Wallops Island	Javelin	Pulse Phase Delay Experiment	J. Ulwick	Partial
5 Jul 66	ETR	Saturn	Saturn Booster Plume Radiation Measurements	J. Lovett	Success
13 Jul 66	WTR	OV1	Cosmic Radiation Satellite Experiment	J. Ely	Failure
13 Jul 66	WTR	Atlas Pod	VLF Propagation (Receiver Group)	P. Newman	Partial
			60 Cycle Radiation Probe	P. Newman	Partial
			VLF Noise Level Measurements	J. Heckscher	Partial
			Radio Frequency Spectrometer	J. Ulwick	Partial
18 Jul 66	ETR	Gemini 10	Ion Aspect Sensor	R. Sagalyn	Success
22 Jul 66	WSMR	Aerobee	Solar Extreme Ultraviolet Monochromator	H. Hinteregger	Success
			Retarding Potential Analyzer	H. Hinteregger	Success
1 Aug 66	WSMR	Nike Apache	Atmospheric Density (7" Falling Sphere)	A. Faire	Success
1 Aug 66	WSMR	Nike Apache	Atmospheric Density (7" Falling Sphere)	A. Faire	Success
6 Aug 66	WSMR	Nike Apache	Atmospheric Density (7" Falling Sphere)	A. Faire	Success
6 Aug 66	WSMR	Nike Apache	Atmospheric Density (7" Falling Sphere)	A. Faire	Success
6 Aug 66	WSMR	Nike Apache	Atmospheric Density (7" Falling Sphere)	A. Faire	Failure
8 Aug 66	CHILL	Aerobee	Cosmic Radiation (Emulsion Packs)	R. Filz	Partial
			Vehicle Dynamics	C. Hoult	Success
9 Aug 66	WTR	Agena	Cosmic Radiation	R. Filz	Success
11 Aug 66	CHILL	Aerobee	Auroral Studies (Spectrometric Technique)	S. Silverman	Success
			Auroral Studies (Photometric Method)	S. Silverman	Partial

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AFCRL ROCKET AND SATELLITE PROGRAM: JULY 1966 - JUNE 1967

Date	Launch Site	Vehicle	Experiment	Scientist	Results
26 Aug 66	Wallops Island	Aerobee	Extreme Ultraviolet Monochromator	H. Hinteregger	Success
			Retarding Potential Analyzer	H. Hinteregger	Success
28 Sep 66	CHILL	Black Brant	Auroral Absorption	J. Sandock	Success
10 Oct 66	APGC	Niro	Atmospheric Density (Expandable Sphere)	G. Faucher	Partial
10 Oct 66	APGC	Niro	Atmospheric Density (Expandable Sphere)	G. Faucher	Failure
14 Oct 66	APGC	Niro	VLF Propagation	E. Lewis	Success
28 Oct 66	ETR	OV3-2	Quadrupole Mass Spectrometer	H. Cohen	Success
			Plasma Probe	M. Smiddy	Success
			Retarding Potential Analyzer	J. Sandock	Success
			RF Probe	J. Ulwick	Success
			Electrostatic Analyzers	J. Ulwick	Success
30 Oct 66	APGC	Nike Cajun	Sky Brightness (Photometers)	R. Toolin	Success
3 Nov 66	ETR	MOLHSQ	ORBIS Low	J. Mullen	Failure
5 Nov 66	Brazil	Nike Hydac	Plasma Probe	R. Sagalyn	Partial
			Solar Eclipse Measurements	J. Ulwick	Success
			Quadrupole Mass Spectrometer	R. Narcisi	Success
11 Nov 66	ETR	Gemini 12	Ion Aspect Sensor	R. Sagalyn	Success
12 Nov 66	Brazil	Nike Hydac	Plasma Probe	R. Sagalyn	Partial
			Solar Eclipse Measurements	J. Ulwick	Success
			Quadrupole Mass Spectrometer	R. Narcisi	Success
12 Nov 66	Brazil	Nike Hydac	Plasma Probe	R. Sagalyn	Partial
			Solar Eclipse Measurements	J. Ulwick	Success
			Quadrupole Mass Spectrometer	R. Narcisi	Success
12 Nov 66	Brazil	Nike Hydac	Plasma Probe	R. Sagalyn	Partial
			Solar Eclipse Measurements	J. Ulwick	Success
			Quadrupole Mass Spectrometer	R. Narcisi	Failure
16 Nov 66	WSMR	Aerobee	Meteor Dust Collection	R. Skrivanek	Failure
26 Nov 66	CHILL	Aerobee	Lunar Infrared Measurements	J. Salisbury	Success
5 Dec 66	WSMR	Aerobee	Infrared Horizon Measurements	C. Cunniff	Success
11 Dec 66	WTR	OV1-9	Exospheric Proton Gyrofrequency	J. Aarons	Success
			Electrostatic Analyzer	L. Katz	Partial
			Geiger Counter	V. Smalley	Success
			Electron Magnetic Analyzer	V. Smalley	Partial
			Proton Spectrometer (PSS1)	V. Smalley	Success
			Proton Spectrometer (PSS2)	V. Smalley	Success
			Electron Spectrometer	V. Smalley	Success
			Proton Range Energy Telescope	V. Smalley	Success
11 Dec 66	WTR	OV1-10	Heavy Primary Detector	J. Ely	Success
			Magnetic Field Measurements	R. Hutchinson	Failure
12 Dec 66	CHILL	Aerobee	Auroral Input-Output	J. Ulwick	Success
			Mass Quadrupole Spectrometer	R. Narcisi	Success
			Cosmic Radiation	L. Katz	Success
12 Dec 66	CHILL	Astrobee 200	Auroral Input-Output	J. Sandock	Success

Appendix C

AFCRL ROCKET AND SATELLITE PROGRAM: JULY 1965 - JUNE 1967

Date	Launch Site	Vehicle	Experiment	Scientist	Results
11 Jan 67	APGC	Niro	Barium Diffusion Rates	N. W. Rosenberg	Failure
16 Jan 67	APGC	Niro	Ionospheric Wind Variations	M. MacLeod	Partial
16 Jan 67	APGC	Niro	Ionospheric Wind Variations	M. MacLeod	Success
16 Jan 67	APGC	Niro	Barium Diffusion Rates	N. W. Rosenberg	Success
17 Jan 67	WSMR	Aerobee	EUV Monochromator	H. Hinteregger	Success
			Retarding Potential Analyzer	H. Hinteregger	Success
19 Jan 67	APGC	Niro	Atmospheric Turbulence (LDF)	R. Lenhard and N. W. Rosenberg	Success
19 Jan 67	APGC	Niro	Atmospheric Turbulence (LDF)	R. Lenhard and N. W. Rosenberg	Failure
23 Jan 67	WSMR	Nike-Apache	Asmospheric Density (7-Inch Falling Sphere)	A. Faire	Partial
23 Jan 67	WSMR	Nike-Apache	Asmospheric Density (7-Inch Falling Sphere)	A. Faire	Success
23 Jan 67	WSMR	Nike-Apache	Asmospheric Density (7-Inch Falling Sphere)	A. Faire	Success
23 Jan 67	WSMR	Nike-Apache	Asmospheric Density (7-Inch Falling Sphere)	A. Faire	Success
26 Jan 67	WSMR	Nike-Apache	Asmospheric Density (7-Inch Falling Sphere)	A. Faire	Partial
31 Jan 67	WTR	OV3-5	Mass Spectrometer (2)	R. Narcisi	Failure
			Ion Density Gauge (3)	J. Ulwick	Failure
			Impedance Probe	J. McIsaac	Failure
4 Mar 67	APGC	Niro	Atmospheric Density (Expandable Sphere)	G. Faucher	Success
5 Mar 67	APGC	Niro	Atmospheric Density (Expandable Sphere)	G. Faucher	Success
8 Mar 67	ETR	OSO-III	Solar Ultraviolet	H. Hinteregger	Success
12 Apr 67	APGC	Niro	Ion Trap	R. Sagalyn	Success
			Mass Spectrometer	R. Narcisi	Success
14 Mar 67	Wallops Island	Aerobee 150	Solar Spectrophotometry (EUV Monochromator)	H. Hinteregger	Partial
22 Mar 67	Wallops Island	Aerobee 150	Solar Spectrophotometry (EUV Monochromator)	H. Hinteregger	Success
12 Apr 67	APGC	Niro	Ion Trap	R. Sagalyn	Success
			Mass Spectrometer	R. Narcisi	Success
12 Apr 67	APGC	Niro	TMA Chemical Release	K. Vickery	Success
12 Apr 67	APGC	Niro	TMA Chemical Release	K. Vickery	Success
13 Apr 67	APGC	Nike Cajun	Ion Trap	R. Sagalyn	Success
13 Apr 67	APGC	Nike Tomahawk	TMA Chemical Release	K. Vickery	Failure
			Falling Sphere	A. Faire	Failure
18 Apr 67	APGC	Niro	Ion Trap	R. Sagalyn	Success
			Falling Sphere	A. Faire	Success
18 Apr 67	APGC	Niro	Ion Trap	R. Sagalyn	Success
			Mass Spectrometer	R. Narcisi	Success
18 Apr 67	APGC	Niro	TMA Chemical Release	K. Vickery	Failure
18 Apr 67	APGC	Niro	TMA Chemical Release	K. Vickery	Failure
19 Apr 67	APGC	Nike Tomahawk	Chemical Release (Ba Clouds)	K. Vickery	Success
27 Apr 67	APGC	Nike Tomahawk	Chemical Release (Ba Clouds)	K. Vickery	Success
28 Apr 67	ETR	OV5-1	Magnetosphere Experiments	G. Yates	Success
7 Jun 67	APGC	Niro	Micrometeoroid Particle Collection	S. Chrest	Failure
23 Jun 67	Wallops Island	Trailblazer II	Reentry Communications	W. Rotman	Success

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Appendix D

AFCRL Organizational History

With the end of World War II, the Radiation Laboratory of MIT and the Radio Research Laboratory of Harvard were closed. These were the leading electronics research centers in the nation at that time, with a complement of scientific talent that few laboratories have ever matched before or since. The closing of the Laboratories threatened the irretrievable scattering and loss of research teams that had worked together during the war years and their programs. To prevent this, the Army Air Force established a recruiting station in Cambridge, Massachusetts, to hire scientific personnel discharged from the two Laboratories. The recruiting station marked the beginning of AFCRL.

13 AUGUST 1945
Recruiters from the Air Technical Service Command's Watson Laboratories, Red Bank, New Jersey, set up offices in Cambridge, Massachusetts, to hire people and obtain projects for assimilation into their organization.

20 SEPTEMBER 1945
The ATS Command set up a research laboratory in Cambridge under the supervision of the Watson Laboratories. It was named Cambridge Field Station.

9 DECEMBER 1947
Cambridge Field Station was separated from Watson Laboratories, reporting to the Air Material Command in Dayton, Ohio.

14 MAY 1948
The Geophysical Research Division of Watson Laboratories moved to the Cambridge Field Station.

5 JULY 1949
The name "Cambridge Field Station" was changed to Air Force Cambridge Research Laboratories.

2 APRIL 1951
AFCRL was transferred to the jurisdiction of the Air Research and Development Command, which became operational on that date.

28 JUNE 1951
The name "Air Force Cambridge Research Laboratories" was changed to Air Force Cambridge Research Center.

SPRING 1952
$5,203,000 was appropriated for construction of new laboratory facilities at L. G. Hanscom Field.

26 APRIL 1954
Laboratory A and B buildings were formally dedicated and occupied by the Electronics Research Directorate of AFCRC.

SPRING 1959
Completion of building C at Hanscom Field permitted closing of Cambridge (Albany Street) buildings.

2 MAY 1960
The name "Air Force Cambridge Research Center" was discontinued and the laboratories became known as Detachment 2 of the Air Force Research Division. Detachment 2 consisted of the Electronics Research and Geophysics Research Directorates.

1 AUGUST 1960
The name "Detachment 2" was changed to the Air Force Cambridge Research Laboratories (the same name used between July 1949 and June 1951).

25 SEPTEMBER 1960
Brig. General B. G. Holzman was appointed AFCRL Commander from his post of Vice Commander, Hq AFRD.

1 APRIL 1961
AFCRL's headquarters command, the Air Force Research Division, was abolished and the Office of Aerospace Research was established as AFCRL's headquarters command. Action was part of a major reorganization of the Air Force R&D structure in which the Air Research and Development Command was abolished and the Air Force Systems Command established.

9 OCTOBER 1961
Internal AFCRL reorganization took place. The separate staffs of the Electronics Research and Geophysics Research Directorates were combined.

15 APRIL 1963
Major realignment of AFCRL organizational elements became effective. The Electronics Research and Geophysics Research Directorates were abolished as organizational entities. The fourteen AFCRL laboratories were consolidated into nine laboratories.

27 OCTOBER 1964
Colonel Leo A. Kiley assumed command of AFCRL from his post as Vice Commander of the Laboratories. Colonel Kiley came to AFCRL in 1963 from the Weapons Effects and Tests Group, DASA, where he served as Deputy Chief of Staff.

18 OCTOBER 1965
Colonel Robert F. Long assumed command of AFCRL replacing Brig. General Leo A. Kiley who became Commander of the AF Missile Development Center. Colonel Long comes to the AFCRL from his post of Commander of the 4th Weather Group, Air Weather Service.

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13. ABSTRACT

This is the fourth in a series of reports on research at the Air Force Cambridge Research Laboratories. The report covers a two-year interval, as will succeeding reports in this unclassified series. This report was written primarily for Air Force and DoD managers of research development—and more specifically, for the managers in our Headquarters office, the Office of Aerospace Research. But it is hoped that it will be of interest and value to a much broader audience. To encompass this broader audience and to make the content more meaningful, the report attempts to relate, by means of survey discussion, the programs to the larger scientific field of which they are a part. The work of each of the nine laboratories is discussed separately in chapters with an overall introductory chapter on AFCRL management and logistic activities during the reporting period.

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